

(12) **United States Patent**  
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(54) **LOW IMPEDANCE OXIDE RESISTANT GROUNDED CAPACITOR FOR AN AIMD**

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See application file for complete search history.

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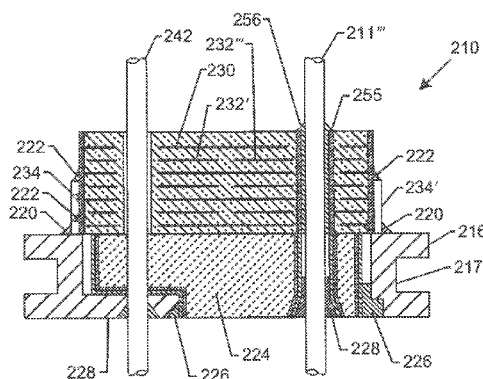
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(57) **ABSTRACT**

A hermetically sealed filtered feedthrough assembly for an AIMD includes an electrically conductive ferrule with an electrically conductive extension at least partially extending into the ferrule opening. An electrically non-conductive insulator hermetically seals the ferrule opening. An electrically conductive pathway is hermetically sealed and disposed through the insulator between a body fluid and device side. A filter capacitor is located on the device side. A first low impedance electrical coupling is between a first metallization of the filter capacitor and the pathway. A ground conductor is disposed through the filter capacitor in non-conductive relation with the at least one active and ground electrode plates, where the ground conductor is electrically coupled to the extension of the ferrule. An oxide-resistant metal addition is disposed on the device side and electrically couples the ground conductor to the second metallization of the filter capacitor.

**28 Claims, 44 Drawing Sheets**



BODY FLUID SIDE

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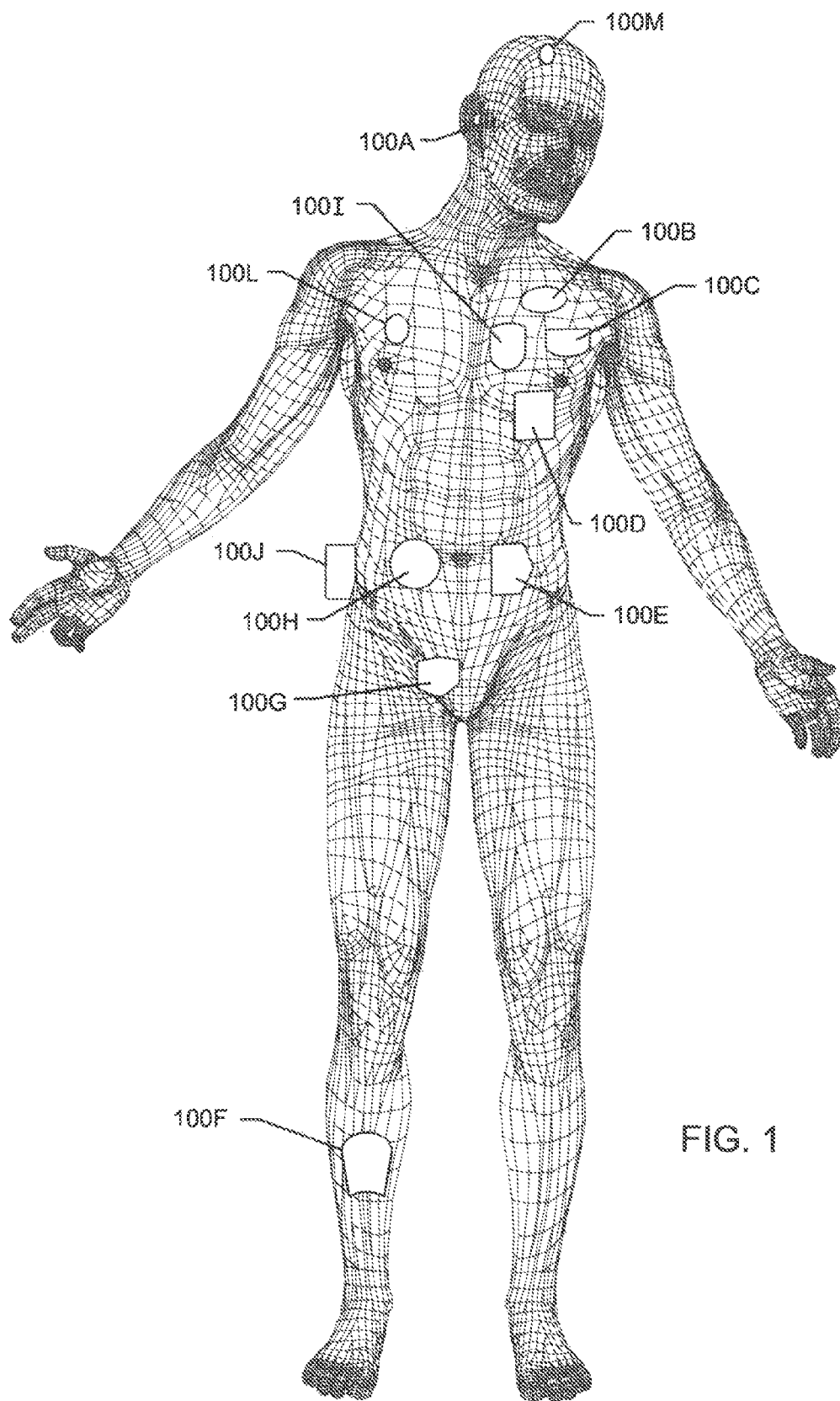
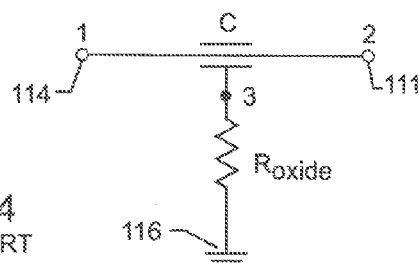
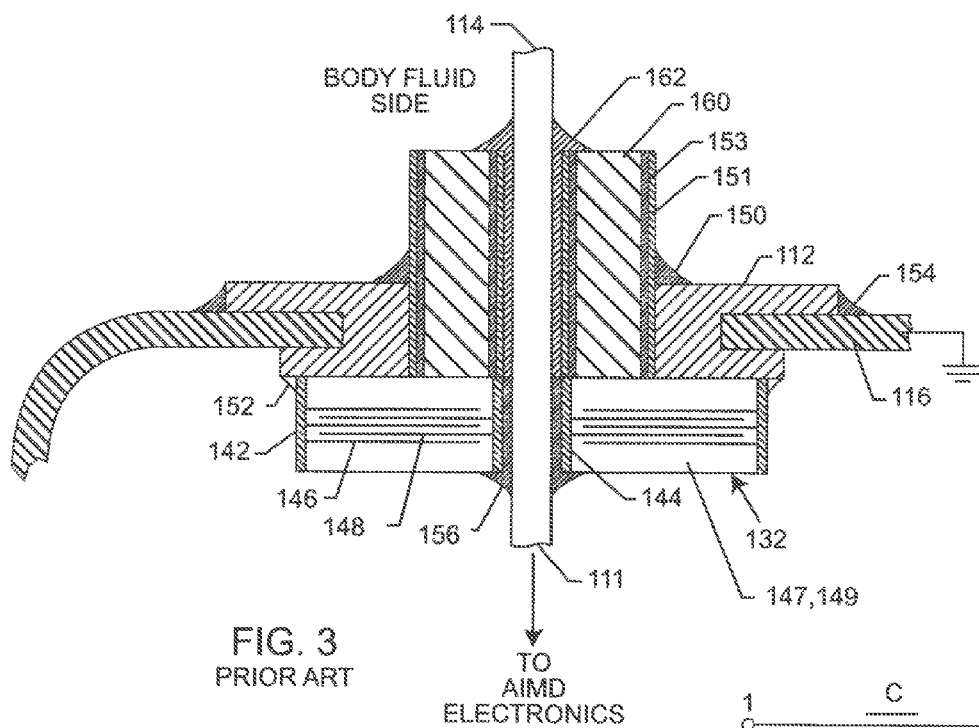
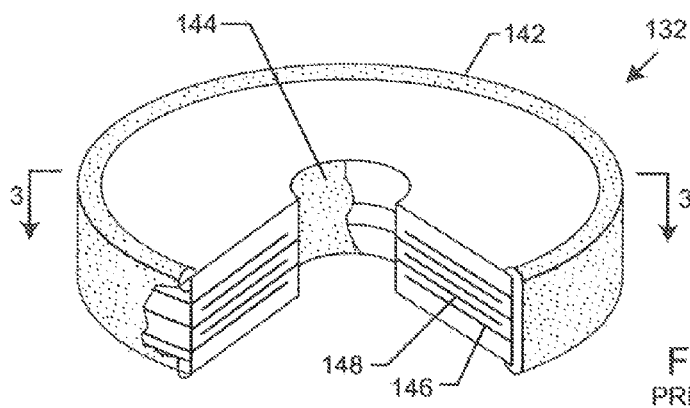


FIG. 1





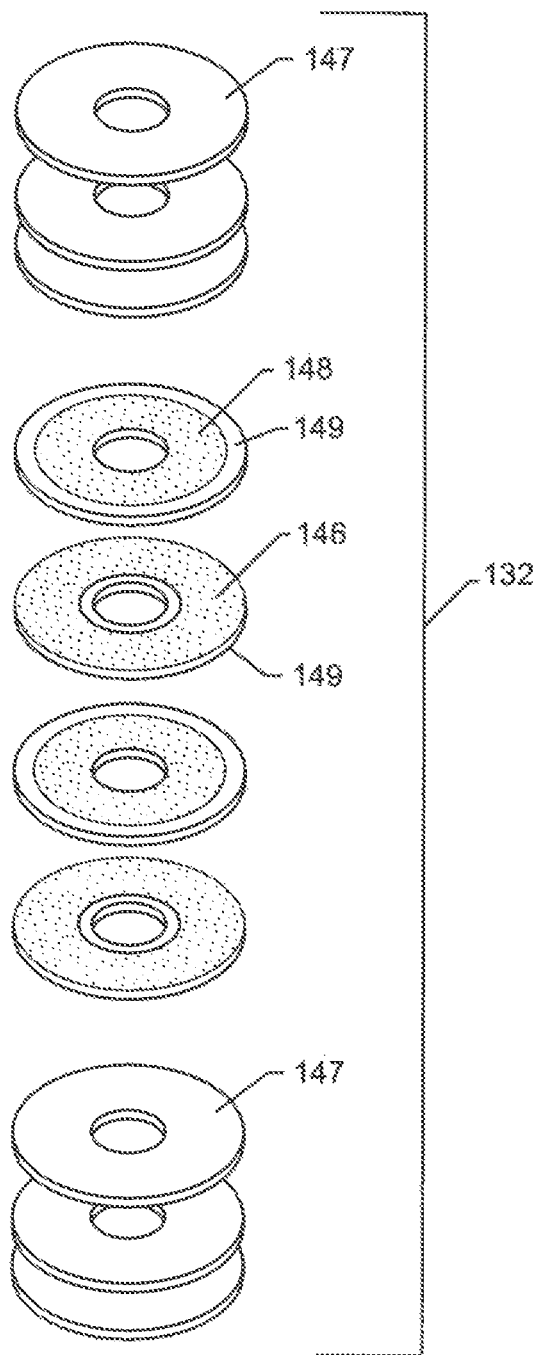
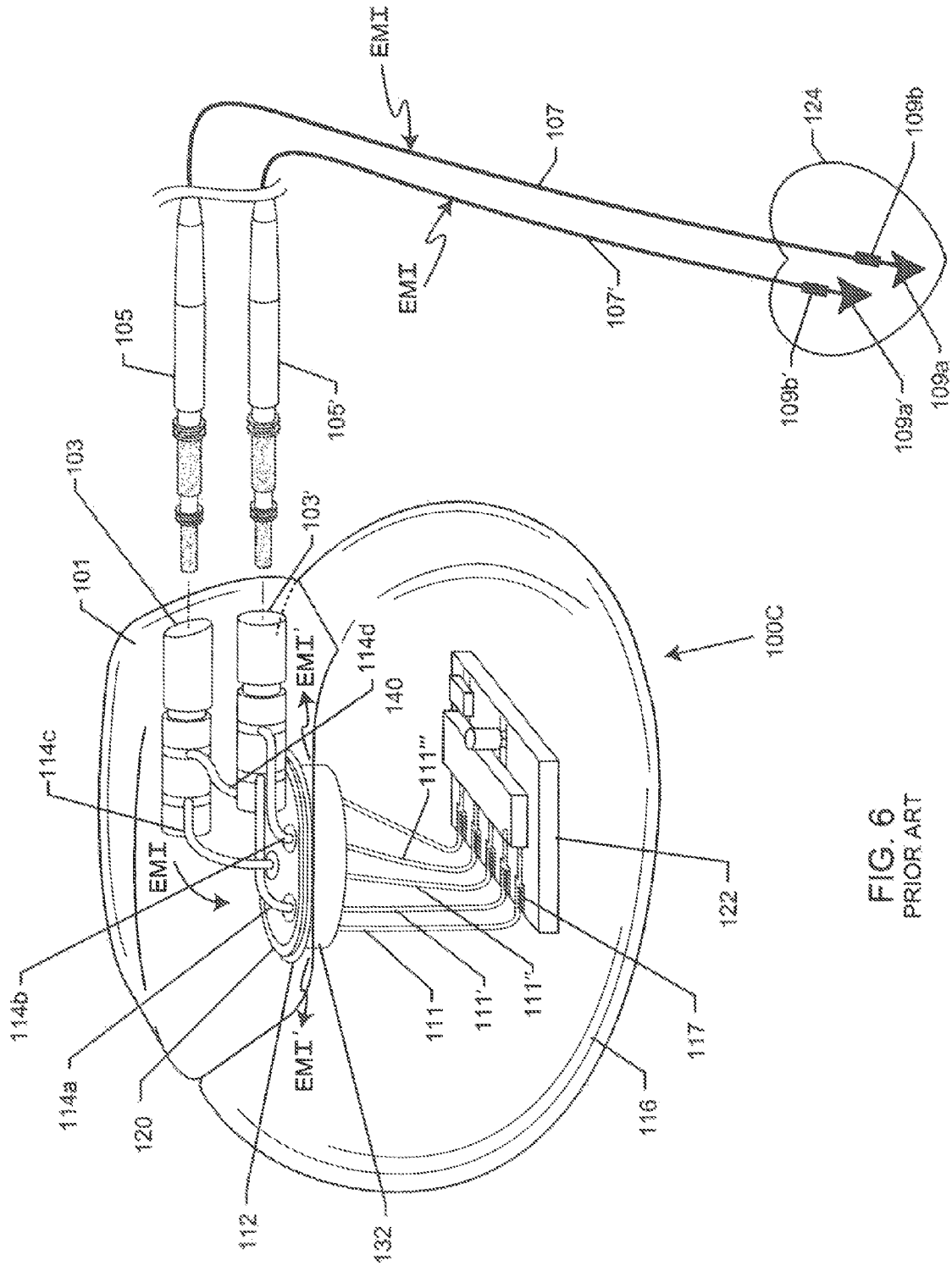


FIG. 5  
PRIOR ART



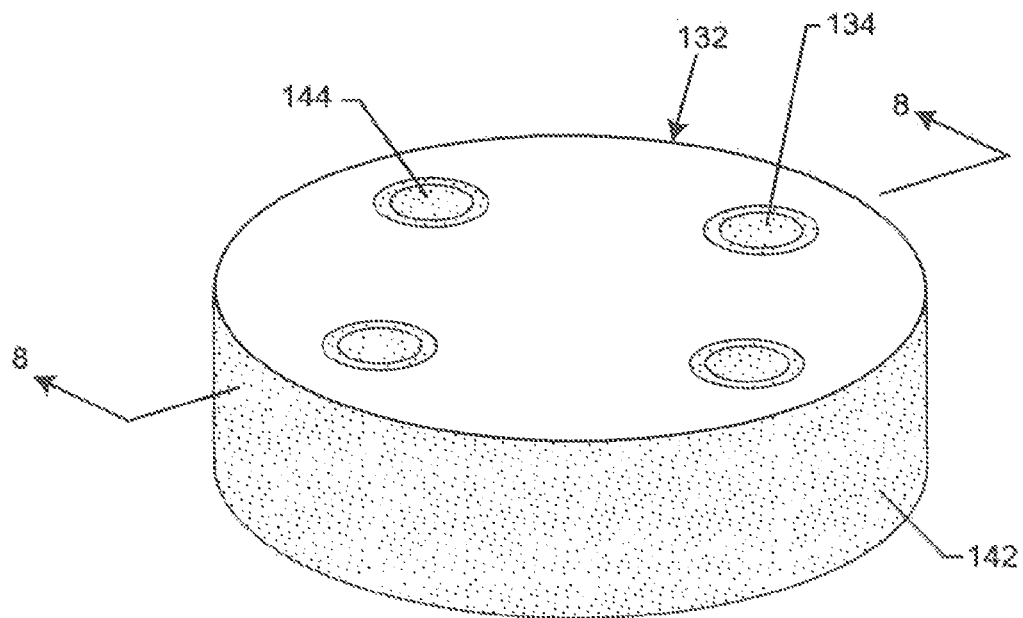


FIG. 7  
PRIOR ART

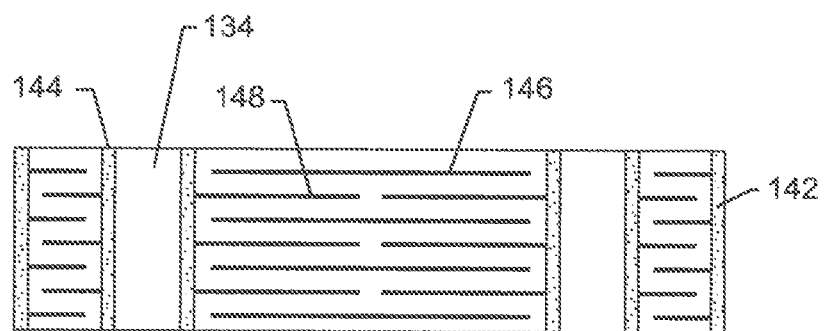


FIG. 8  
PRIOR ART

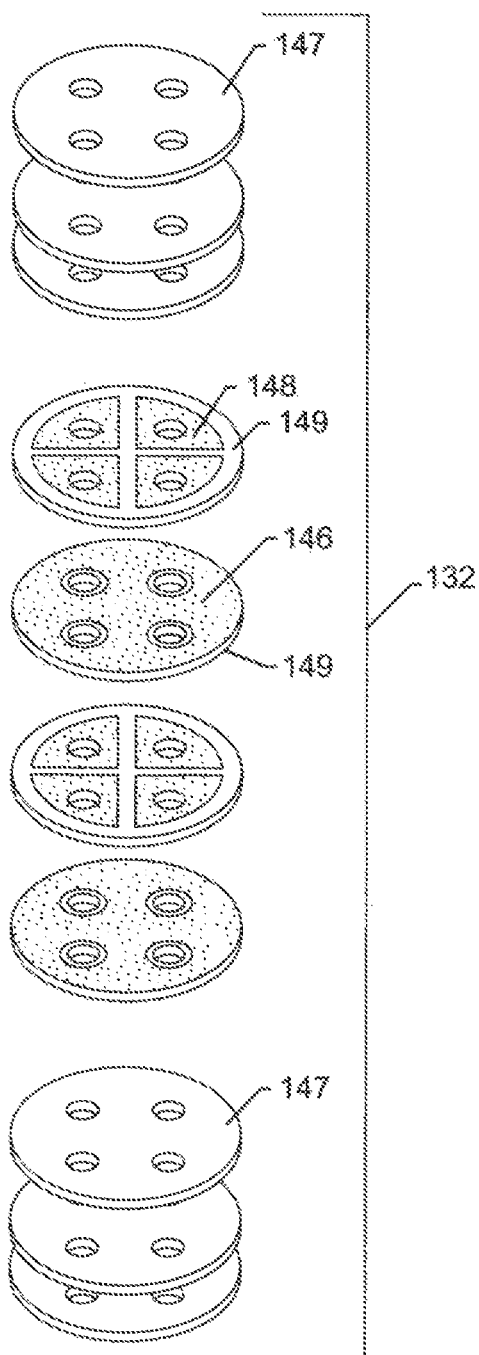


FIG. 9  
PRIOR ART

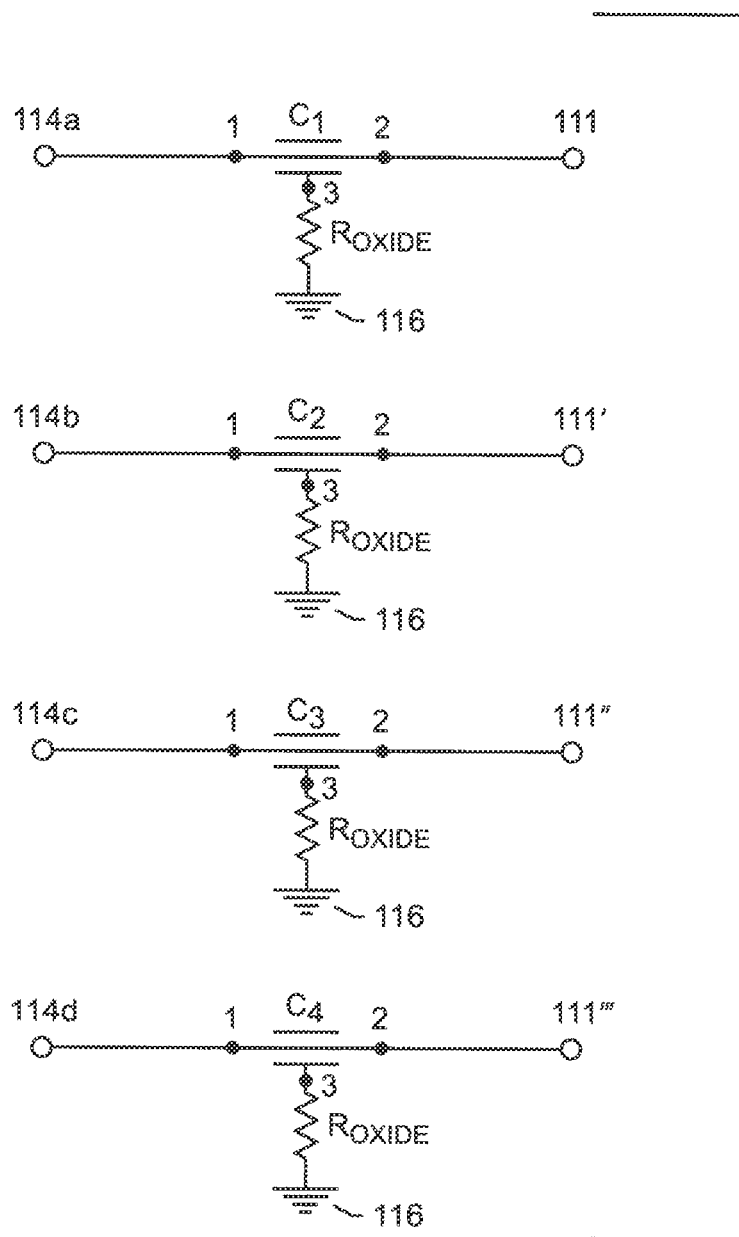


FIG. 10  
PRIOR ART

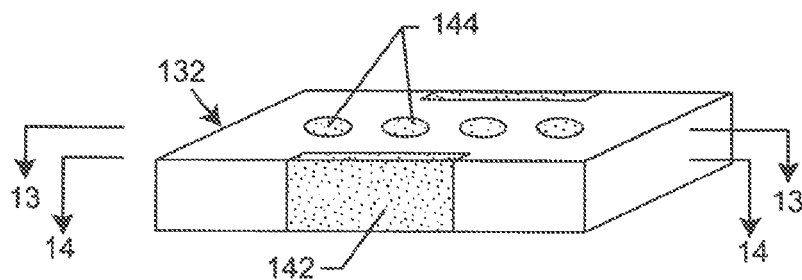


FIG. 11  
PRIOR ART

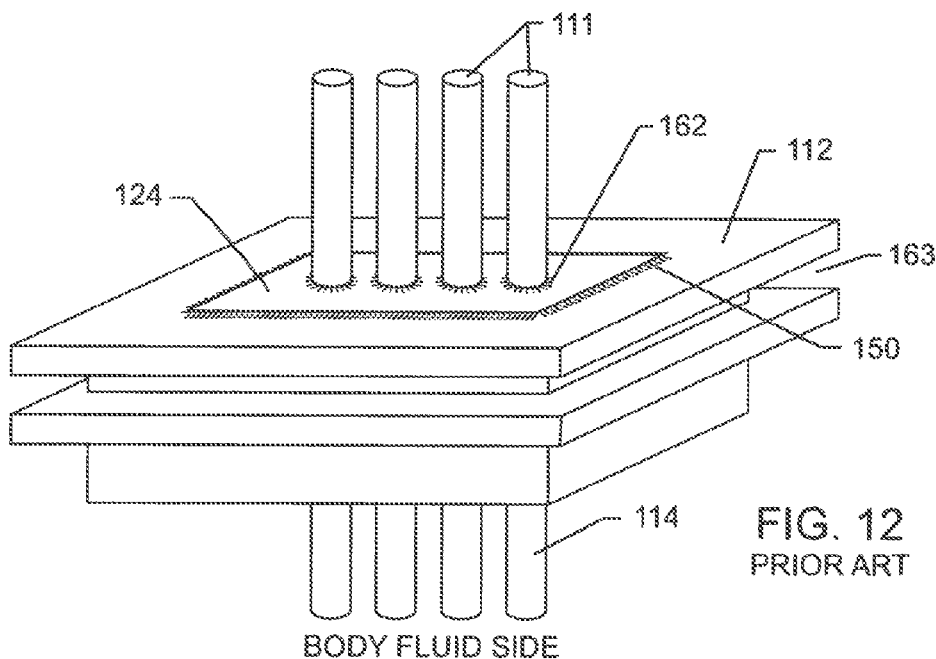


FIG. 12  
PRIOR ART

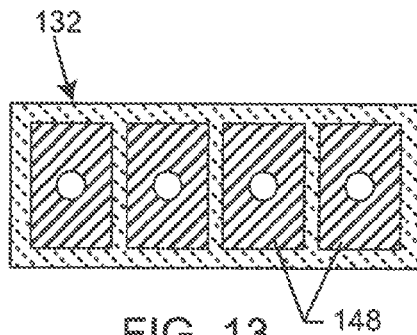


FIG. 13  
PRIOR ART

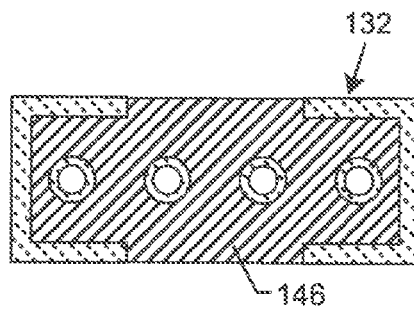
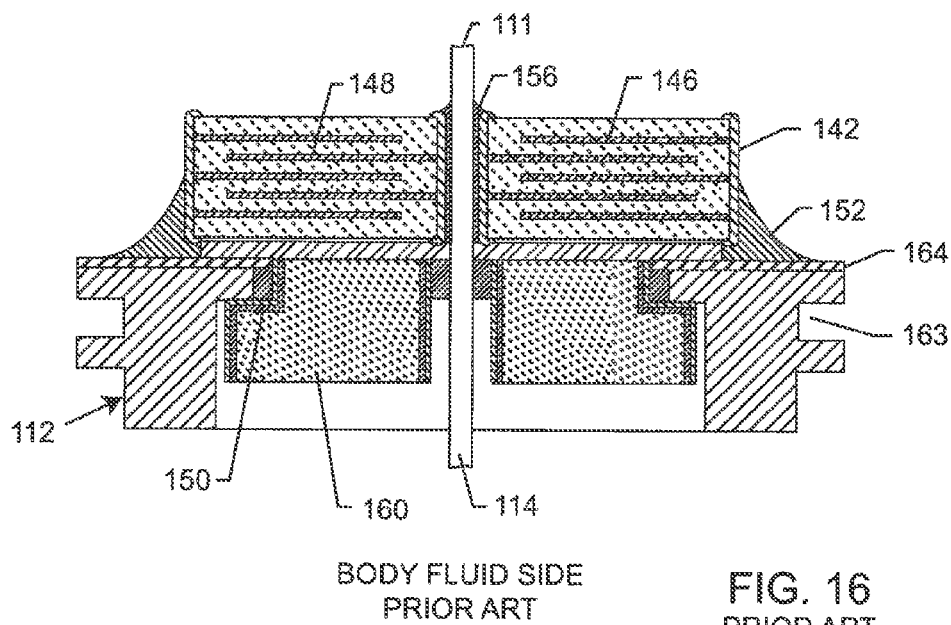
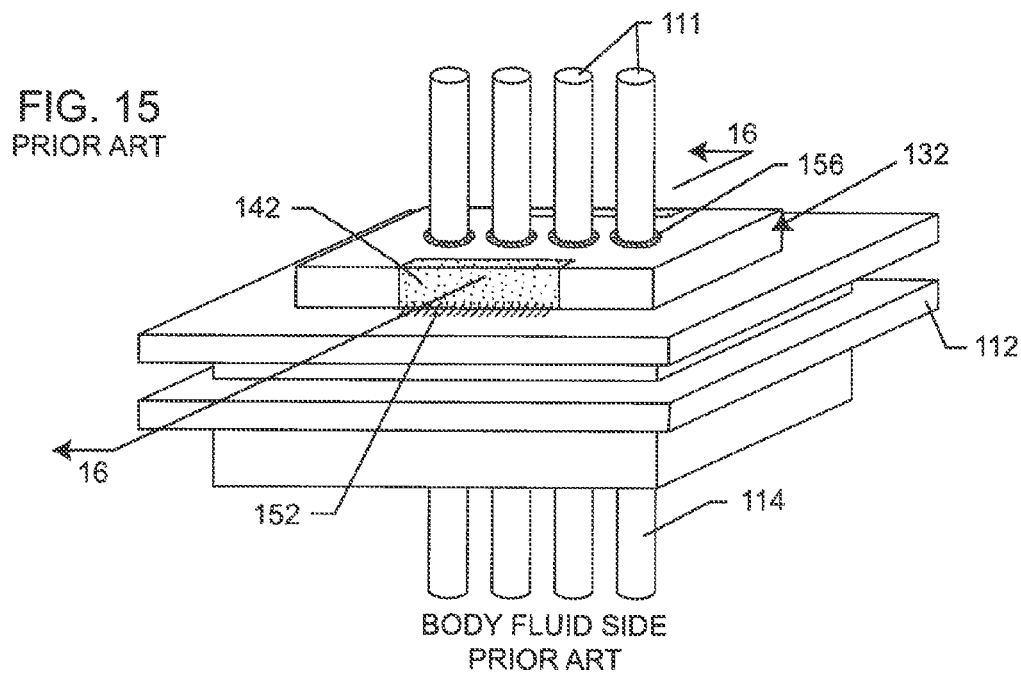


FIG. 14  
PRIOR ART



**FIG. 16**  
PRIOR ART

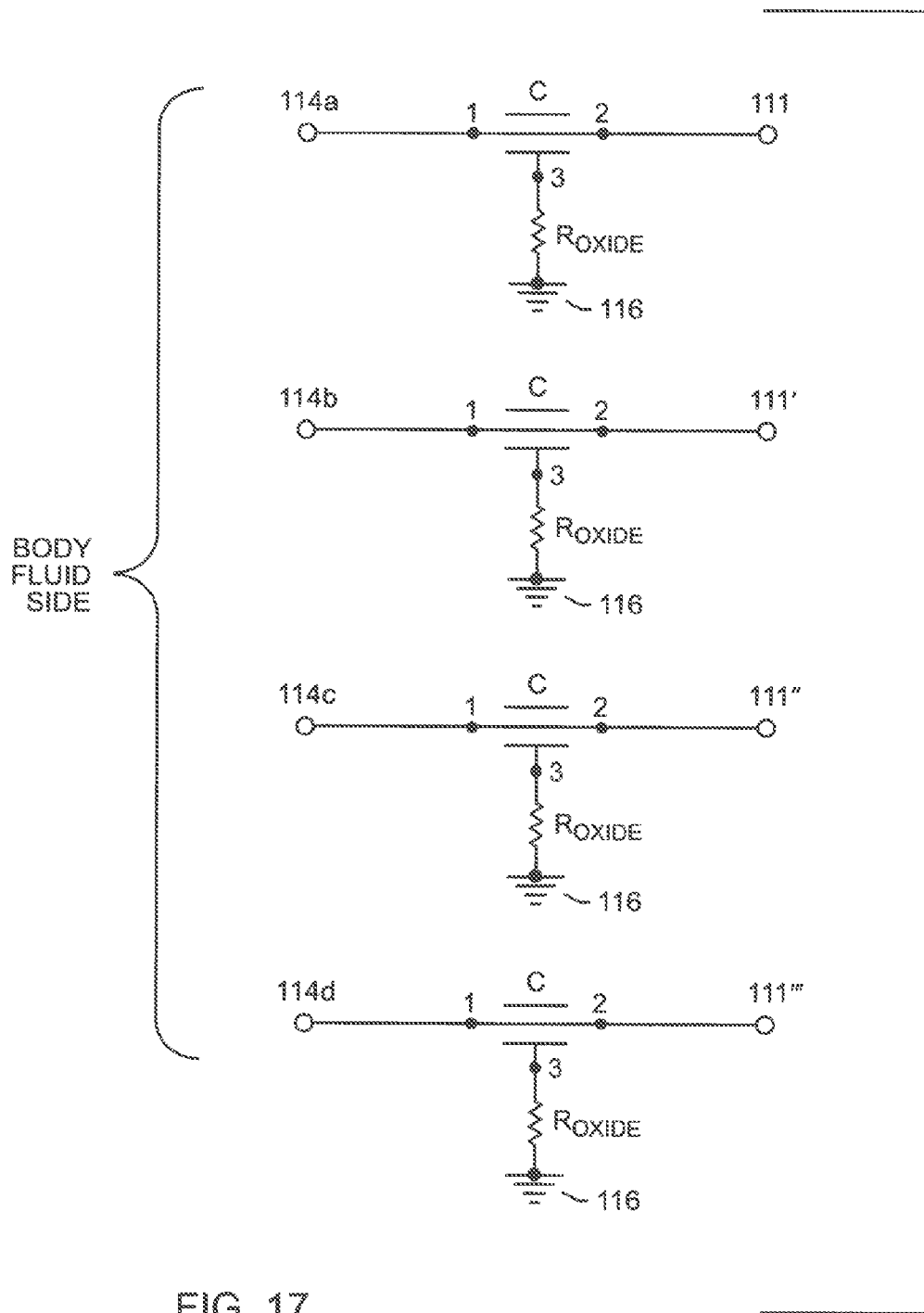


FIG. 17  
PRIOR ART



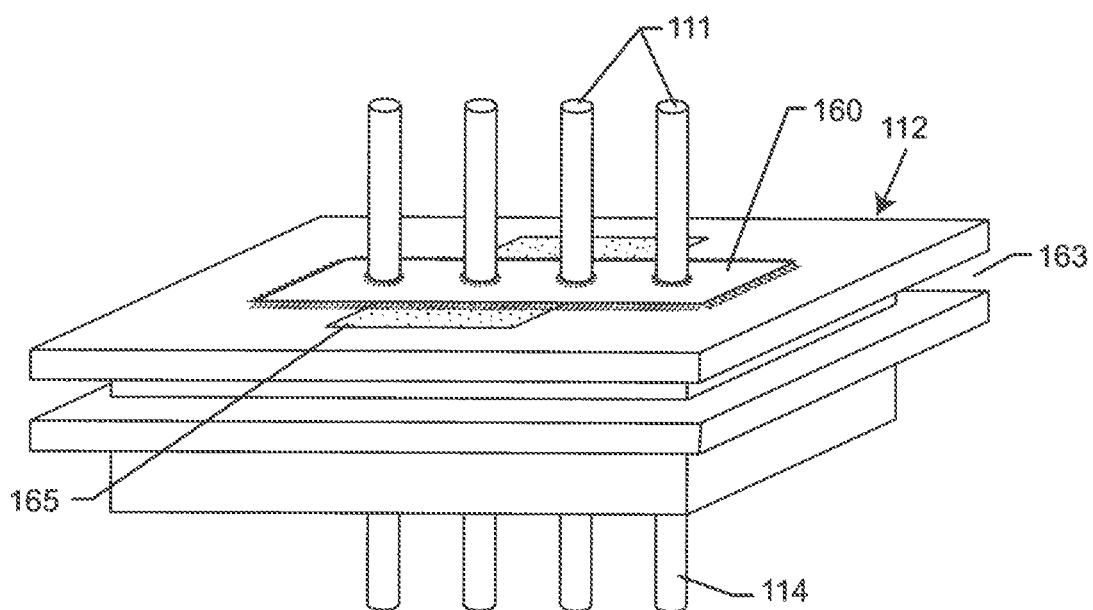


FIG. 18  
PRIOR ART

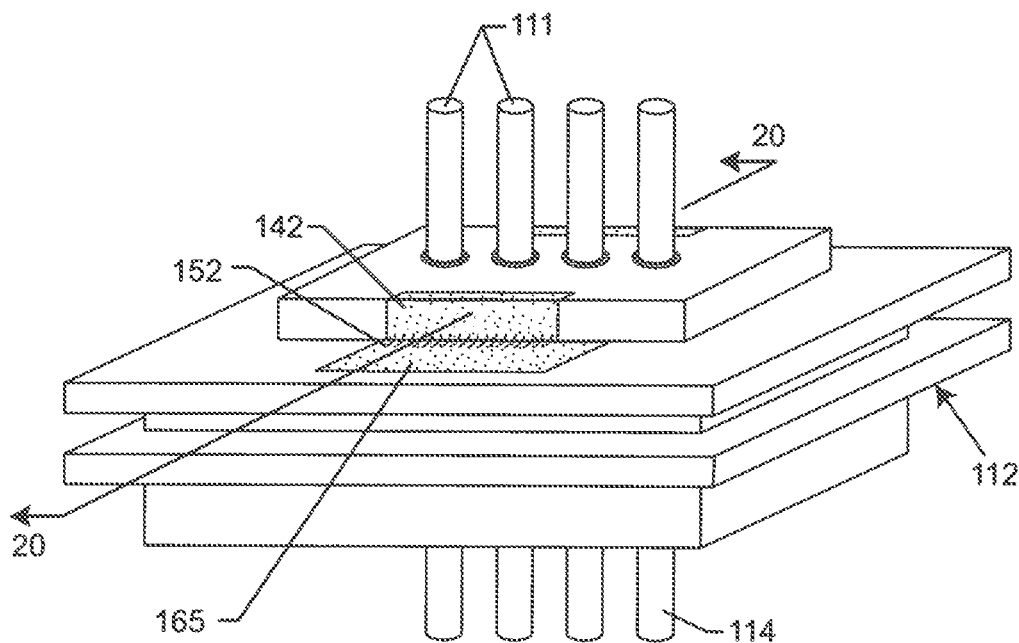


FIG. 19  
PRIOR ART

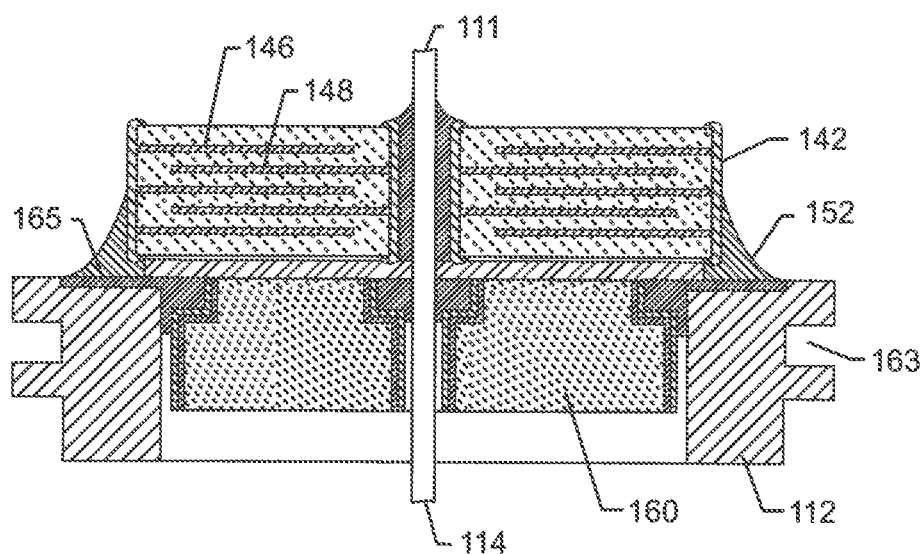


FIG. 20  
PRIOR ART

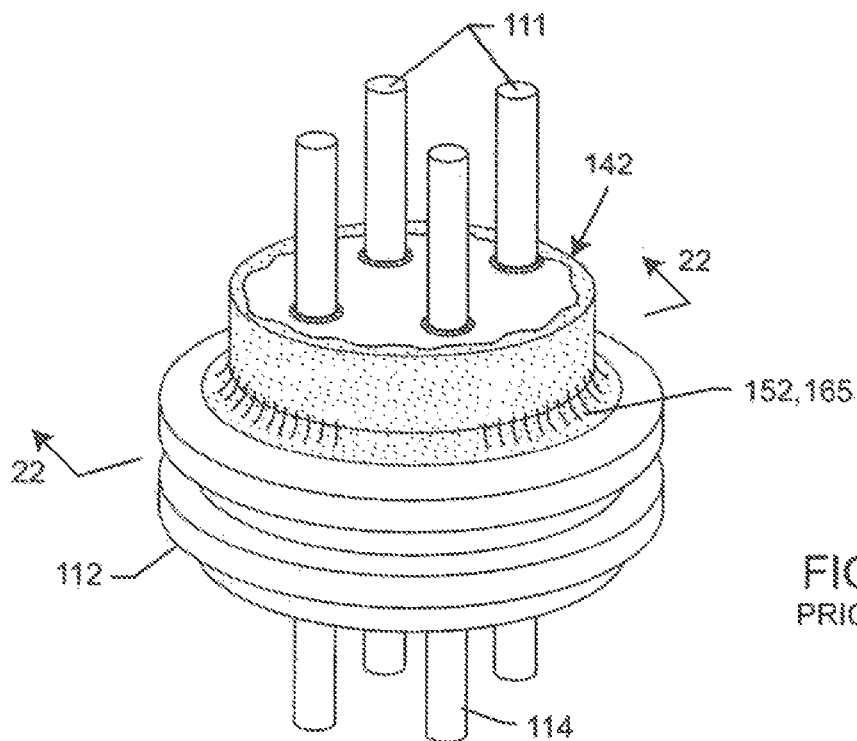


FIG. 21  
PRIOR ART

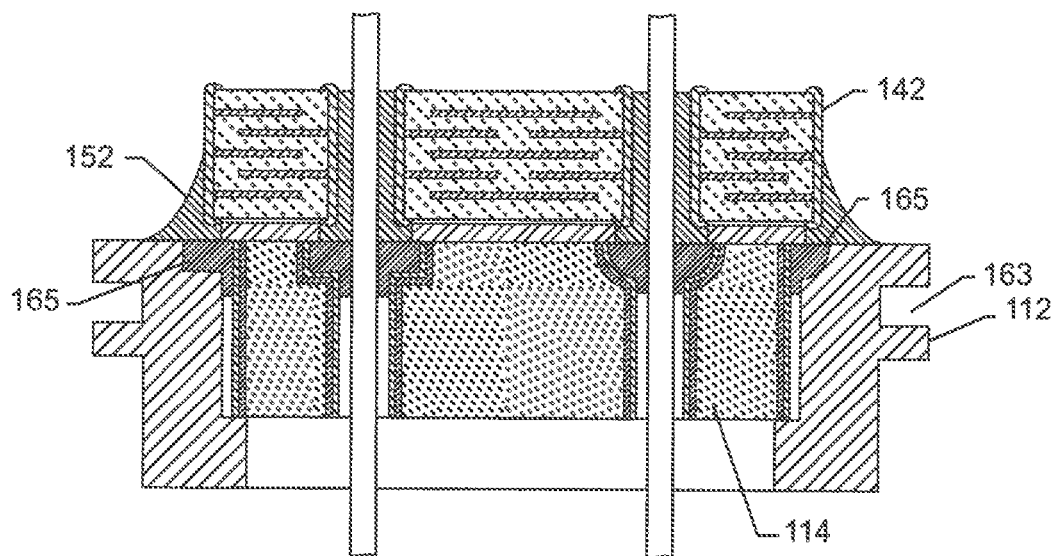


FIG. 22  
PRIOR ART

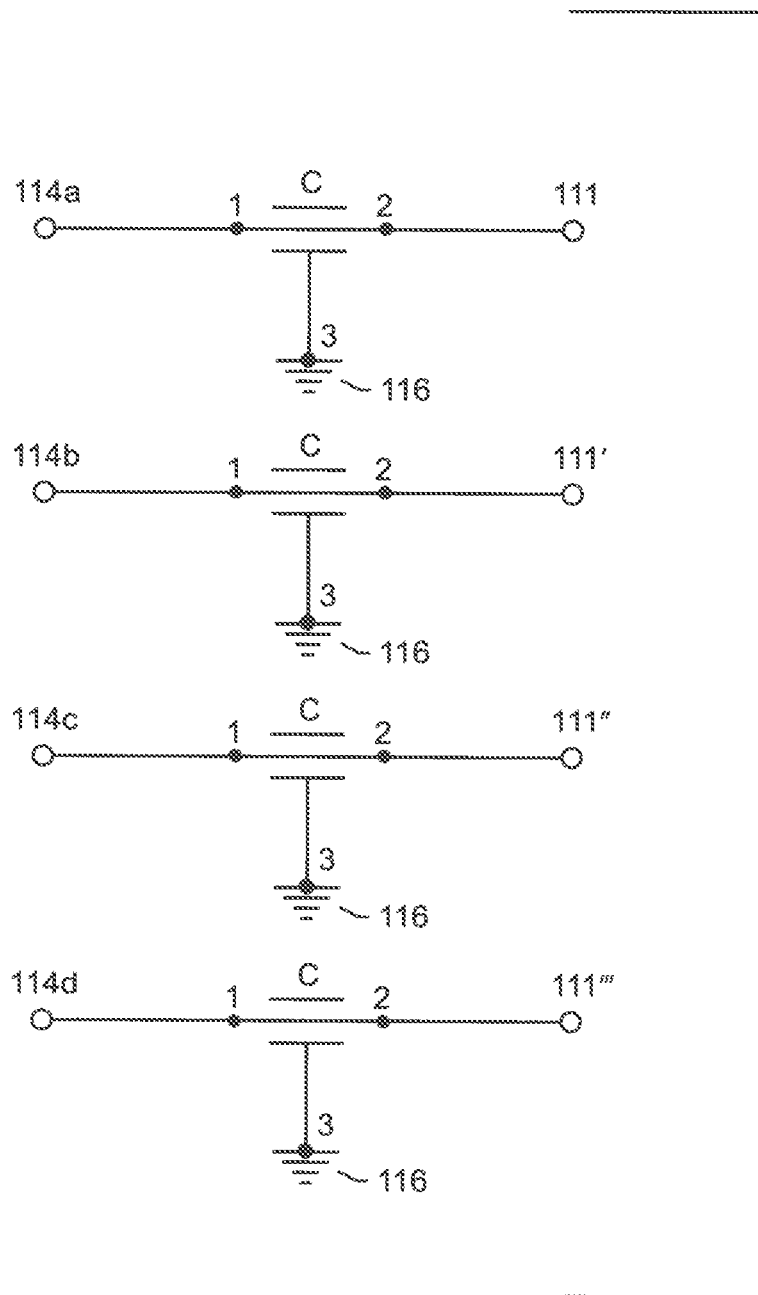


FIG. 23  
PRIOR ART

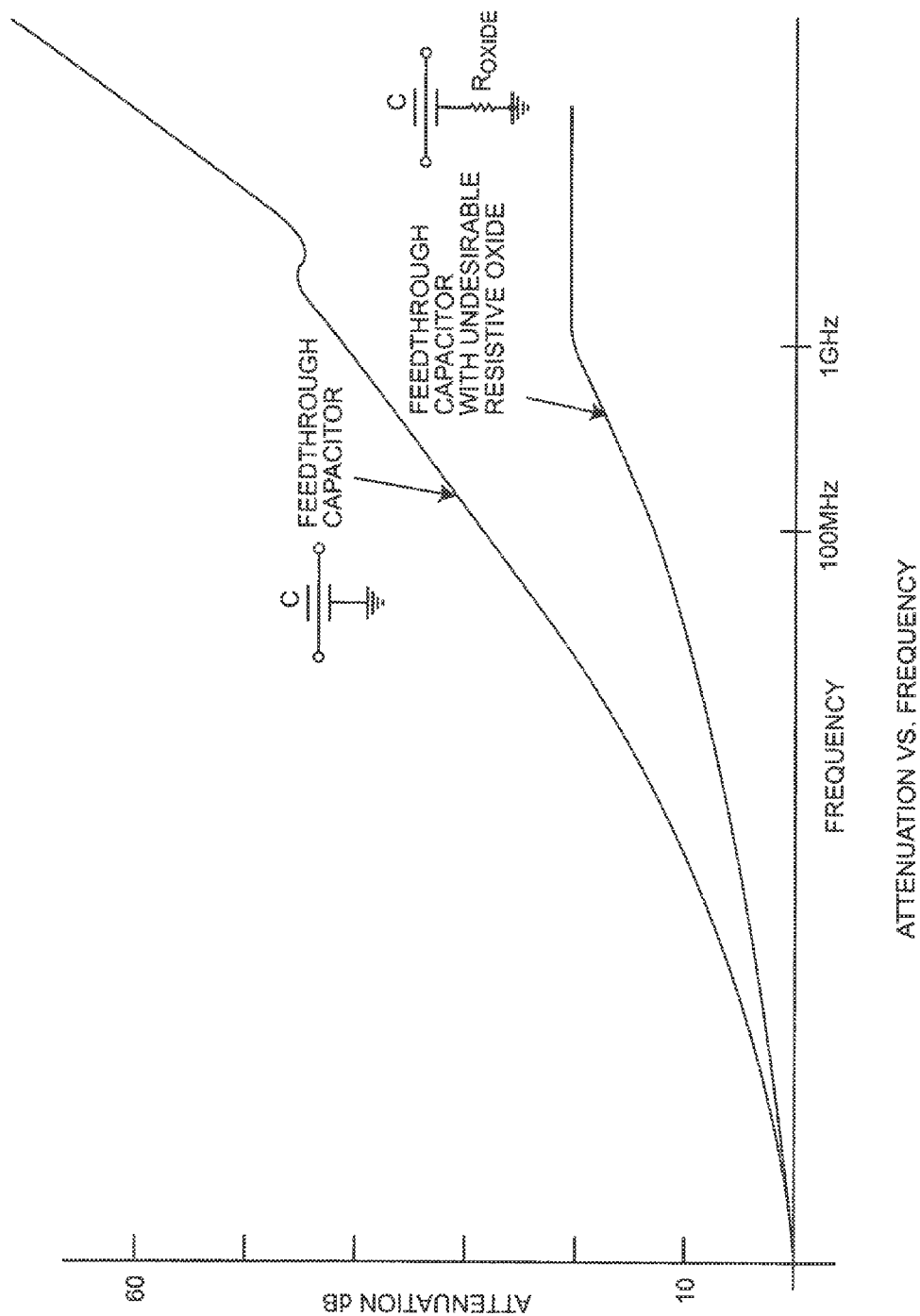
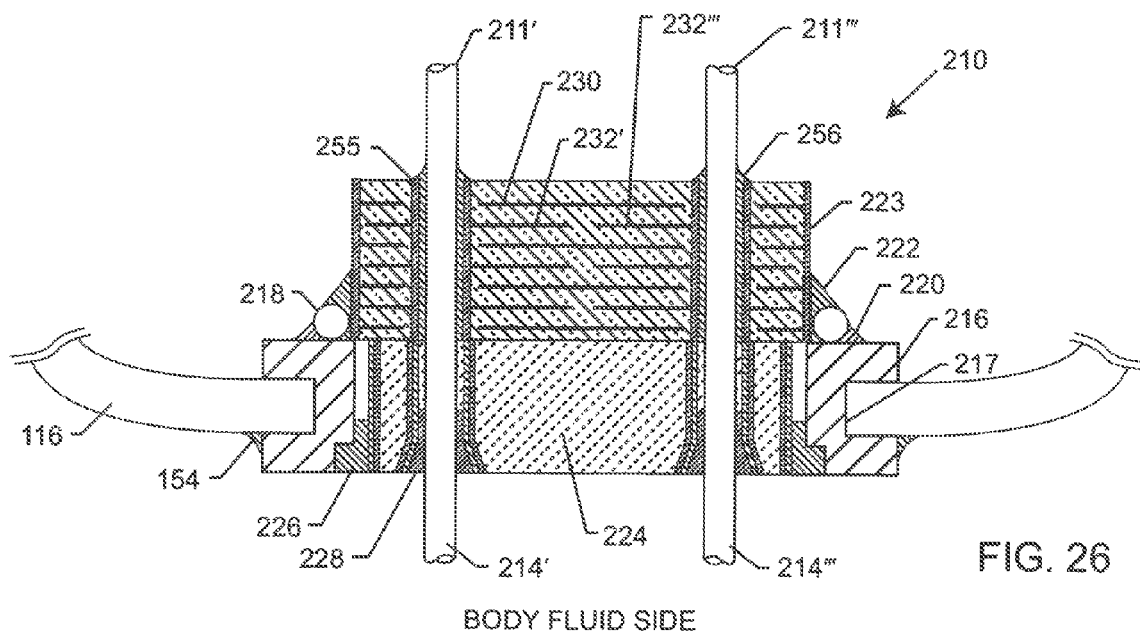
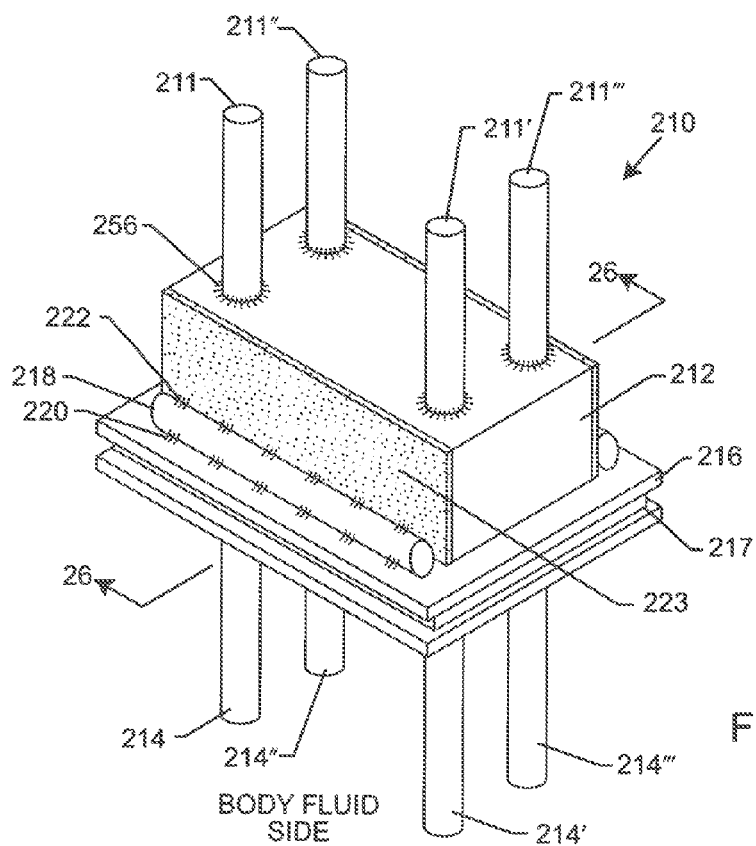


FIG. 24  
PRIOR ART



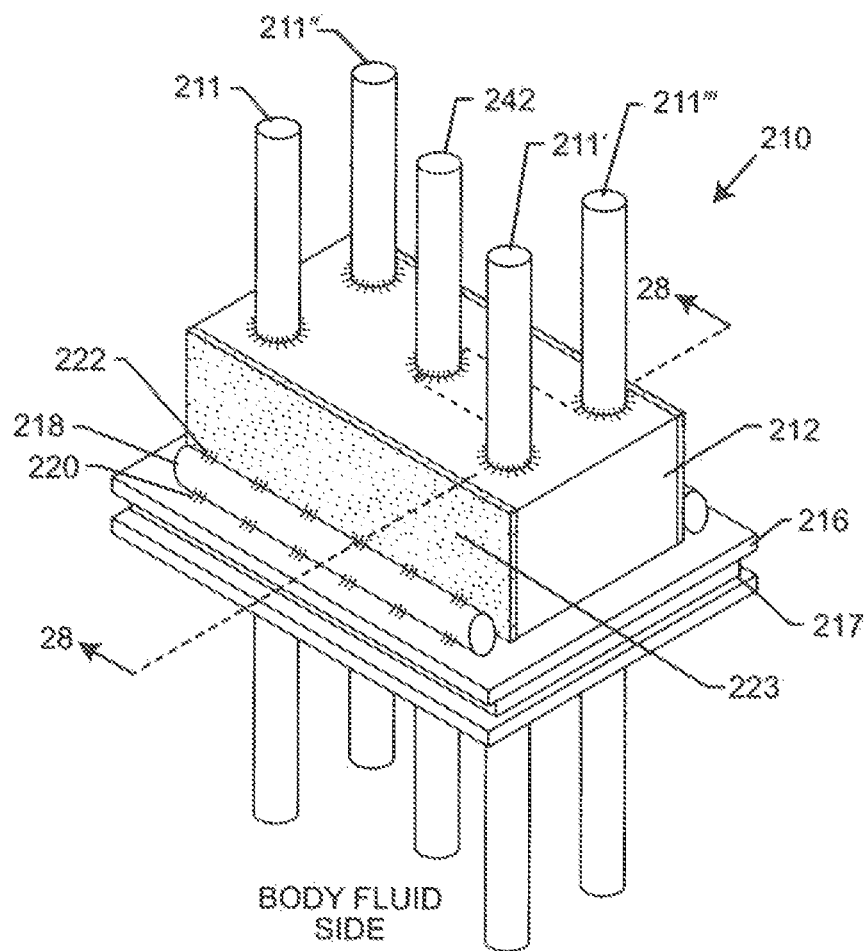
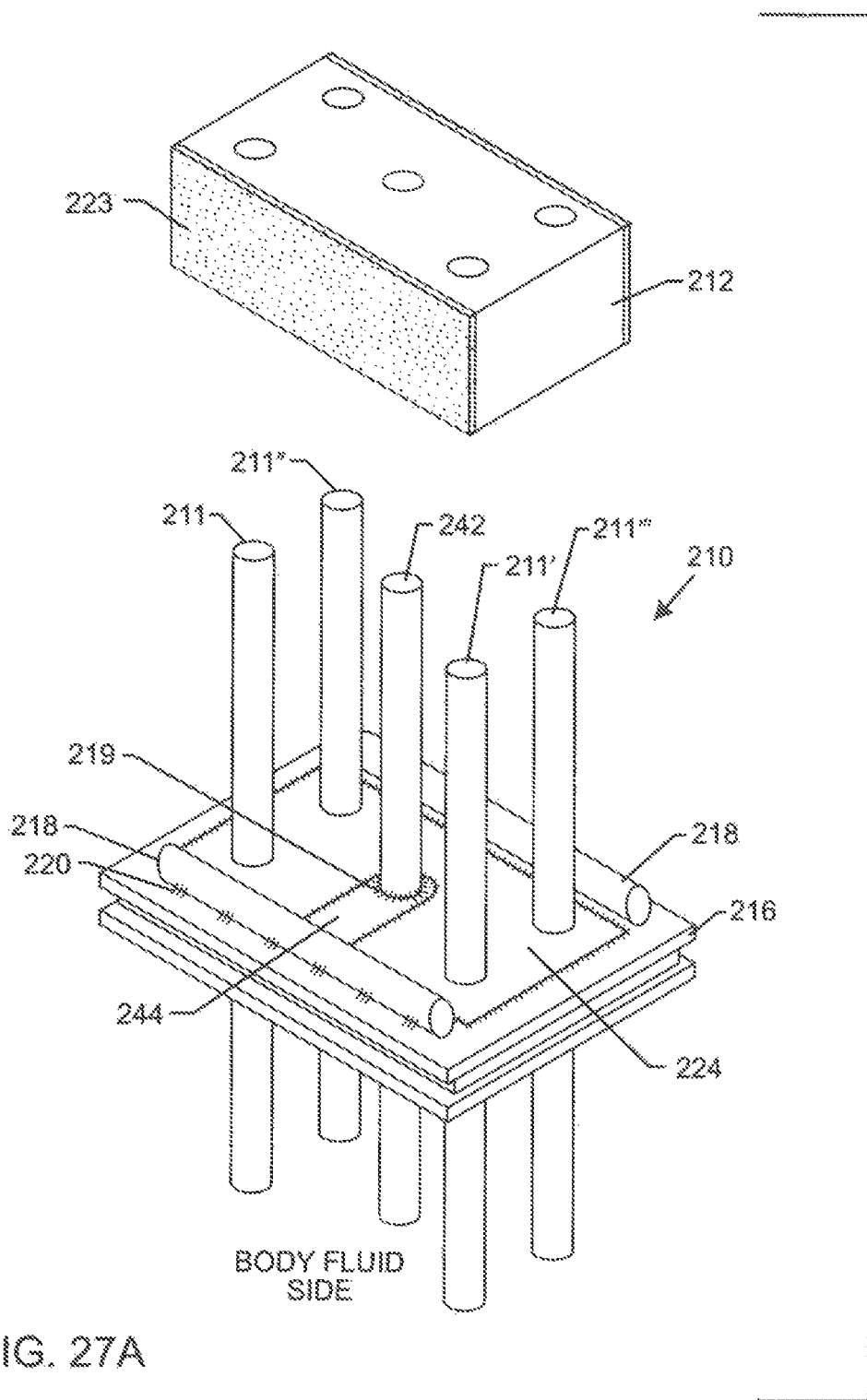


FIG. 27





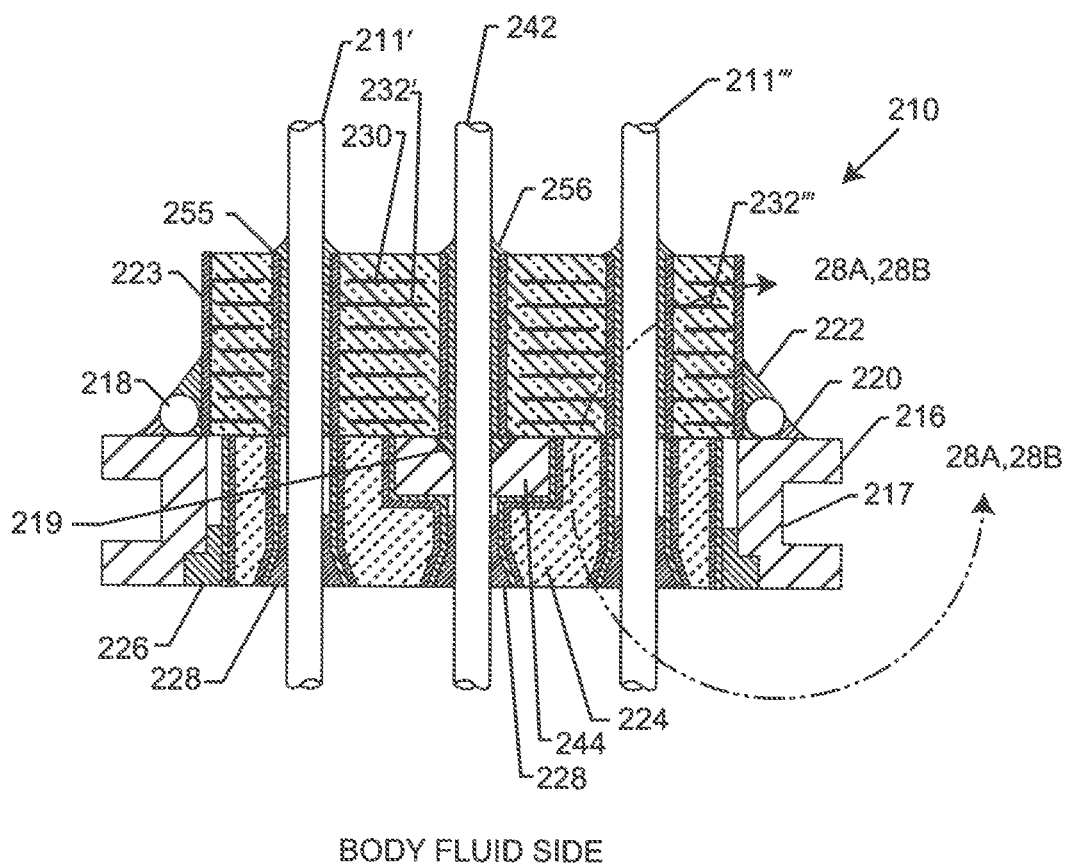


FIG. 28

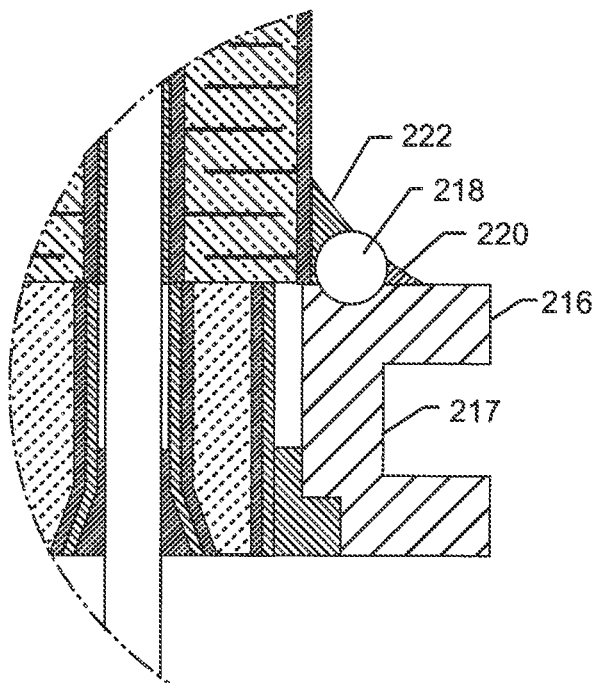


FIG. 28A

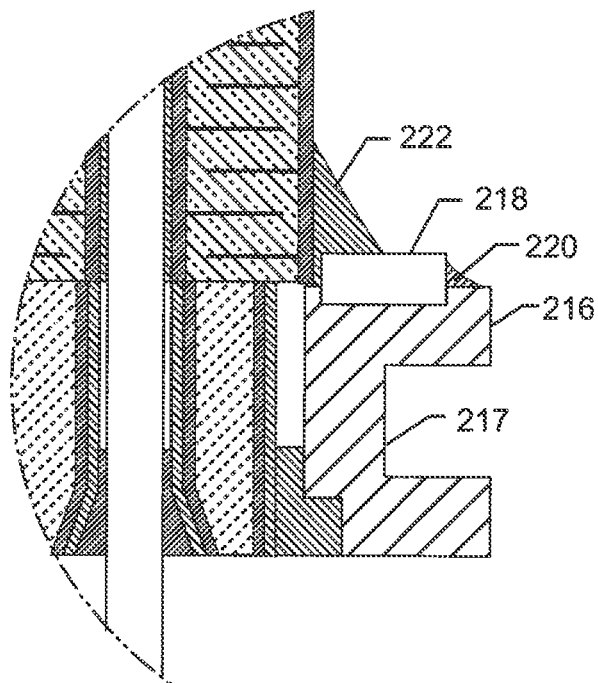
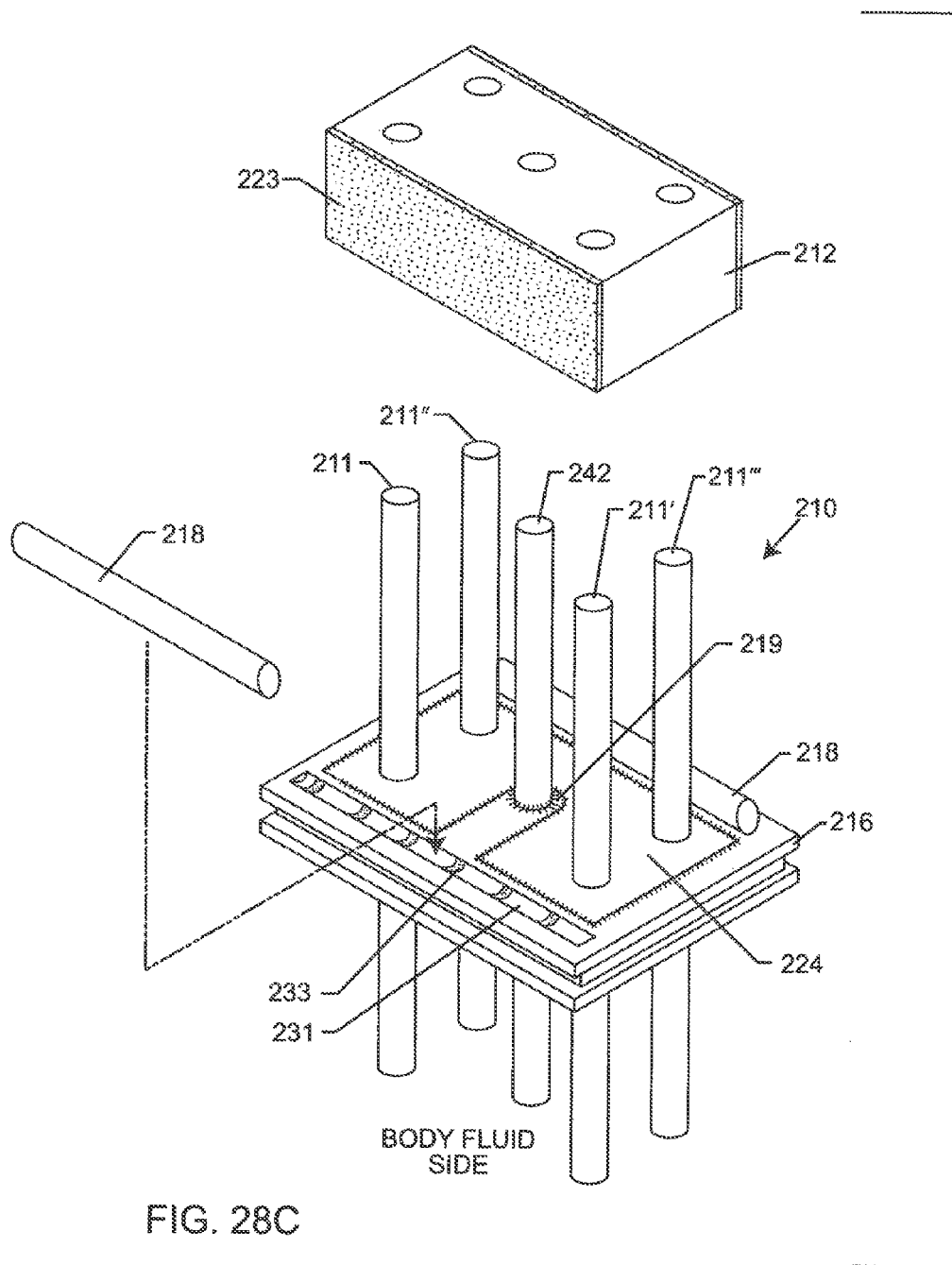
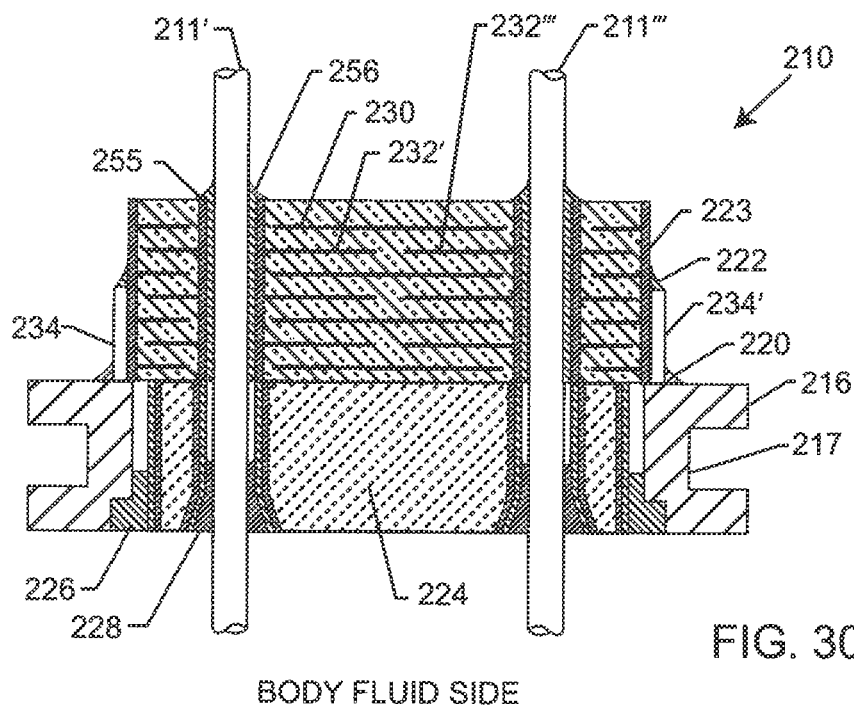
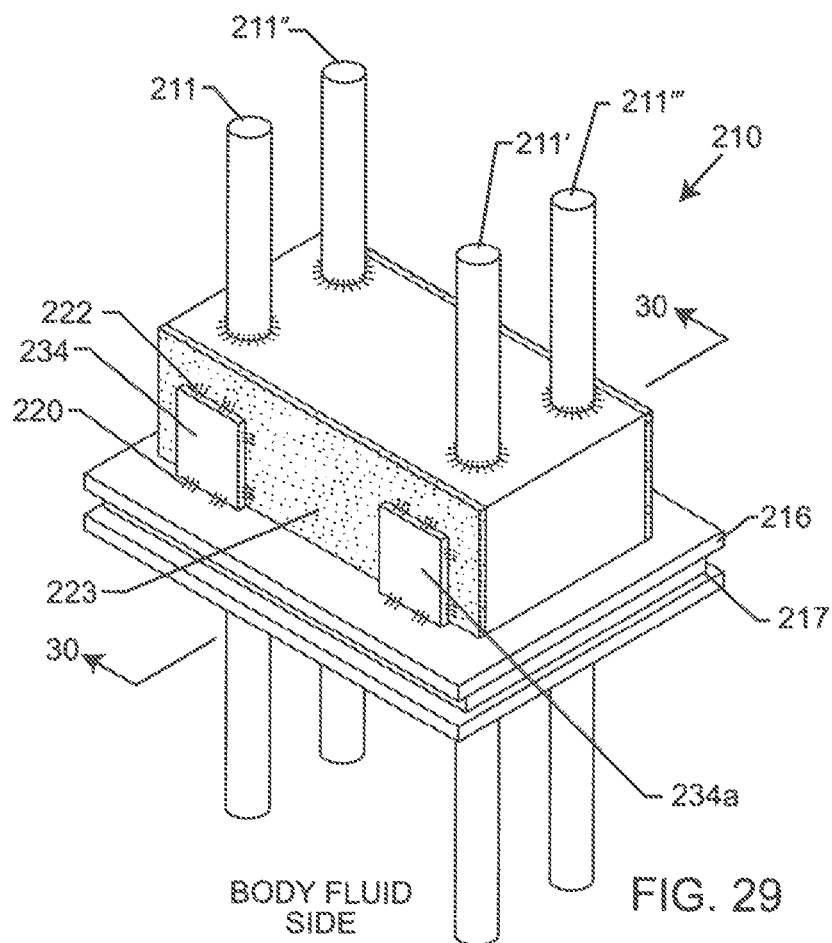
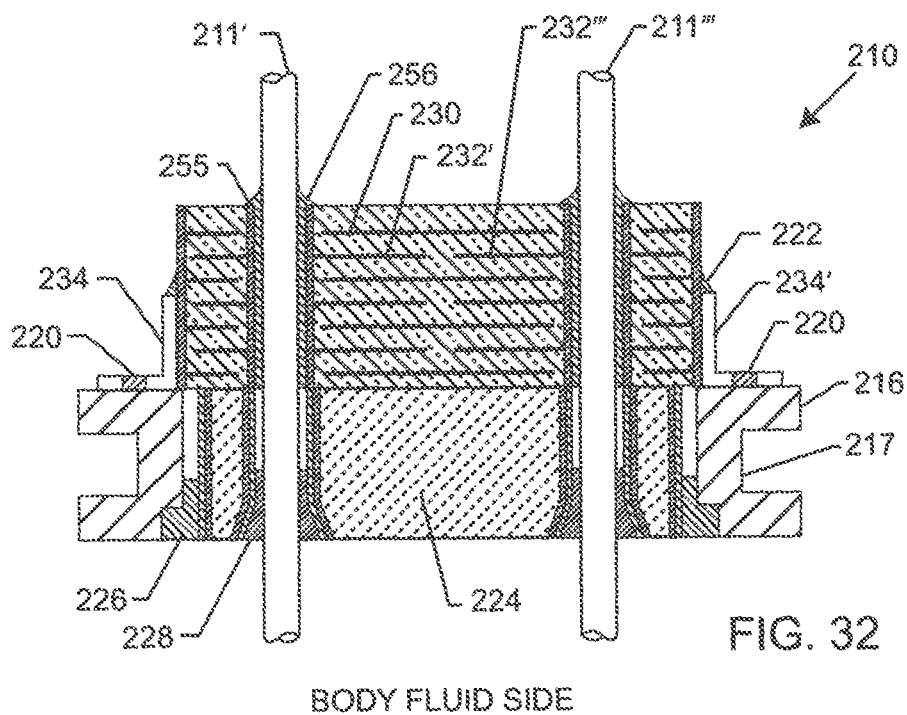
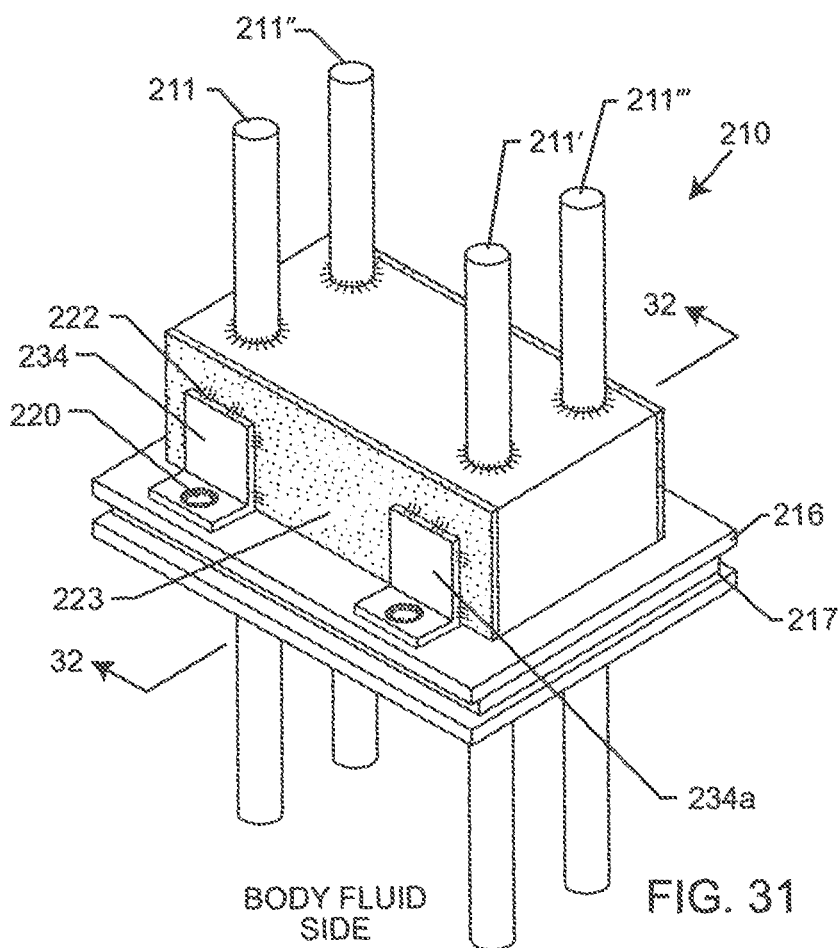


FIG. 28B







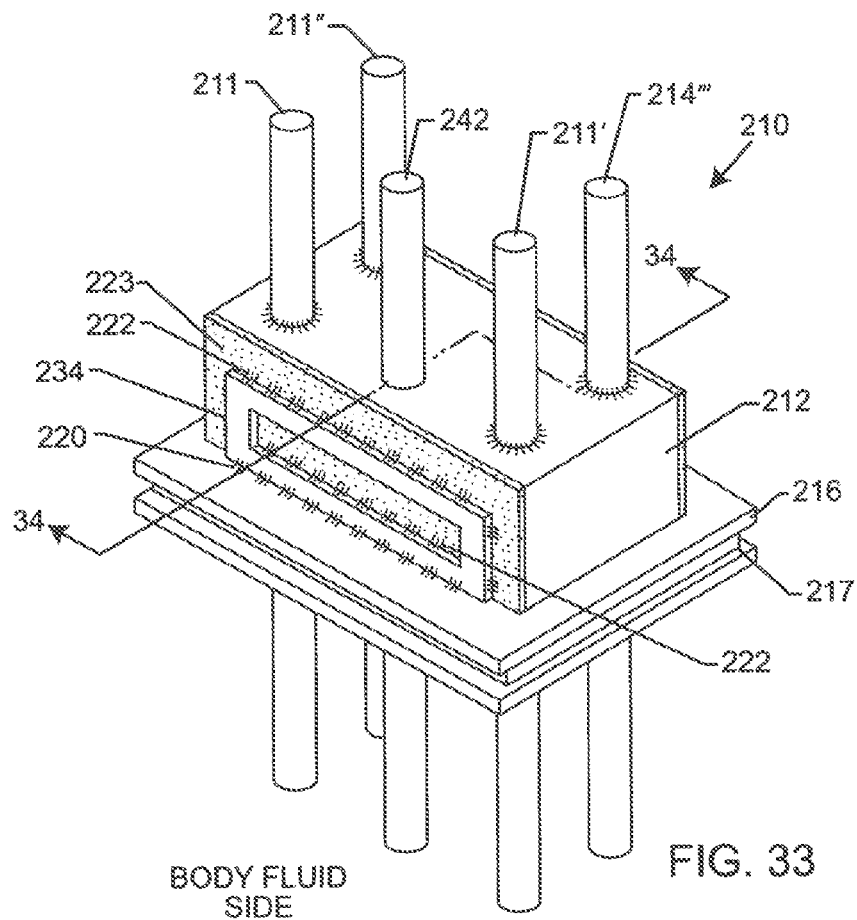


FIG. 33

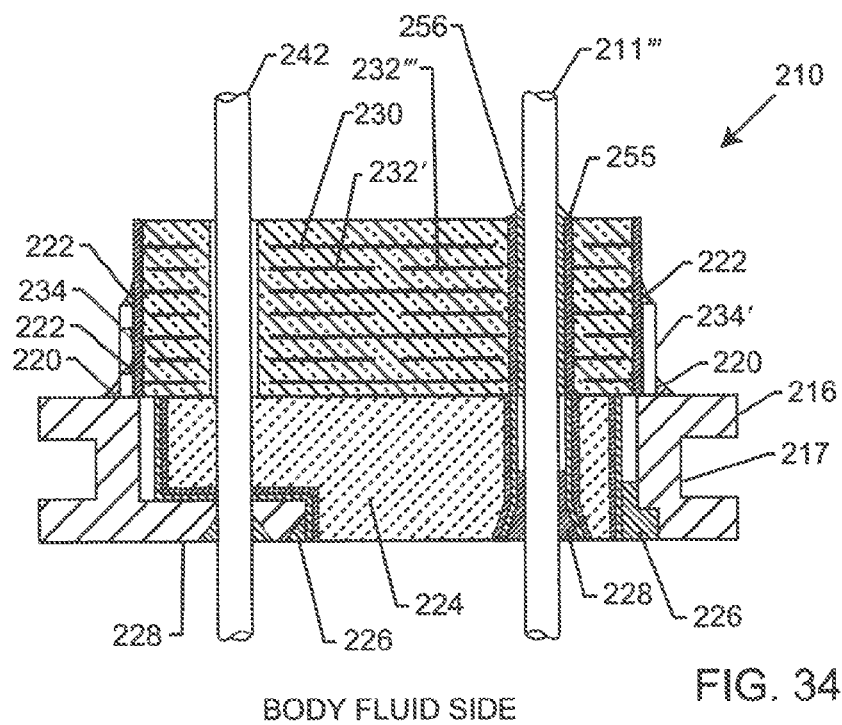


FIG. 34

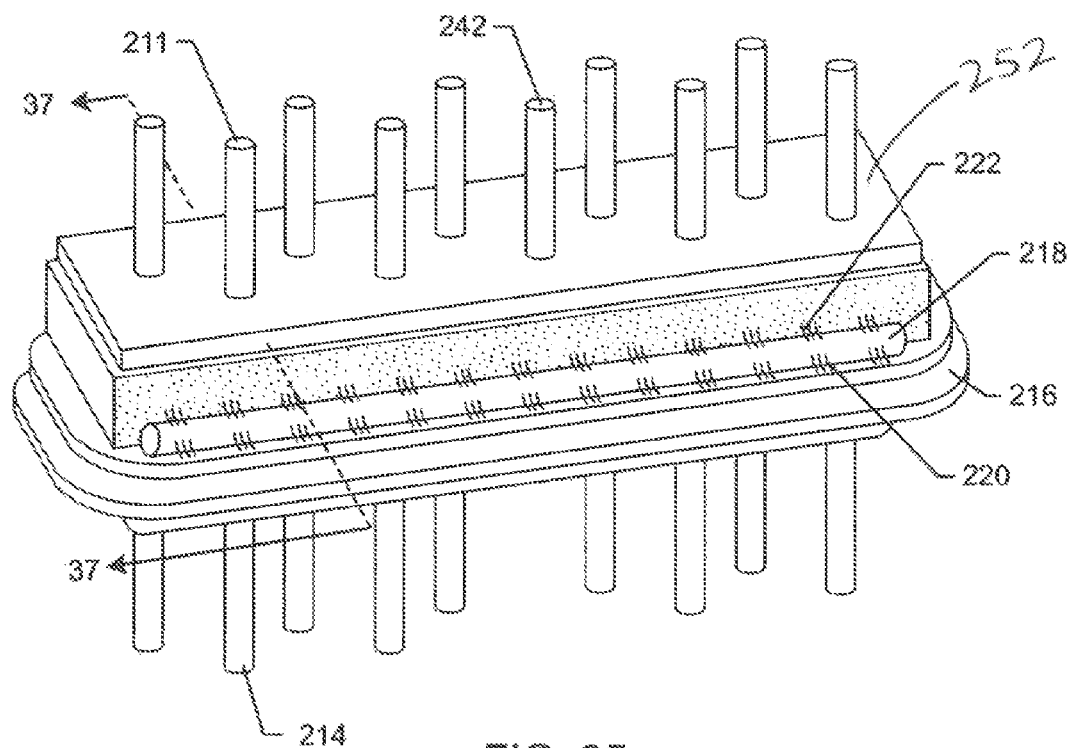


FIG. 35

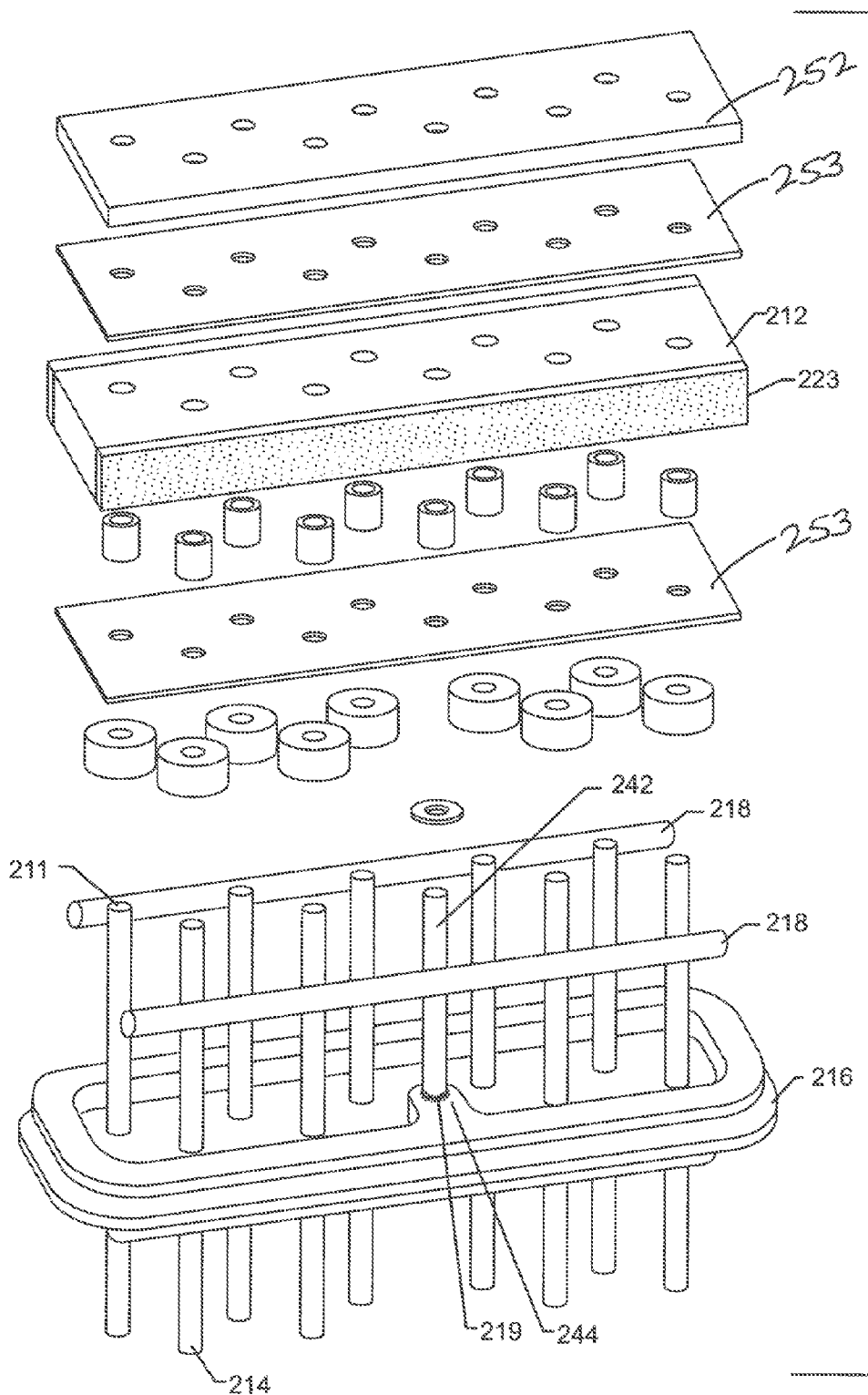


FIG. 36



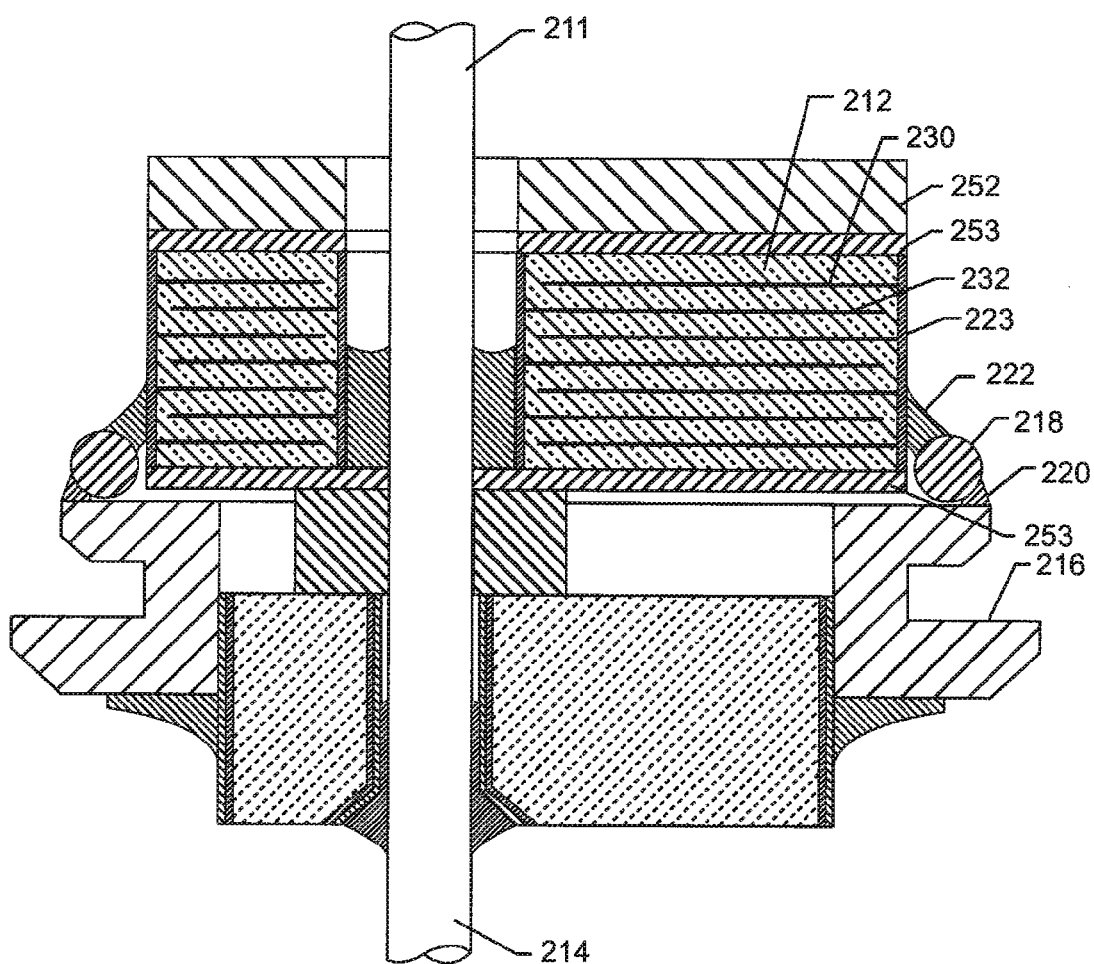
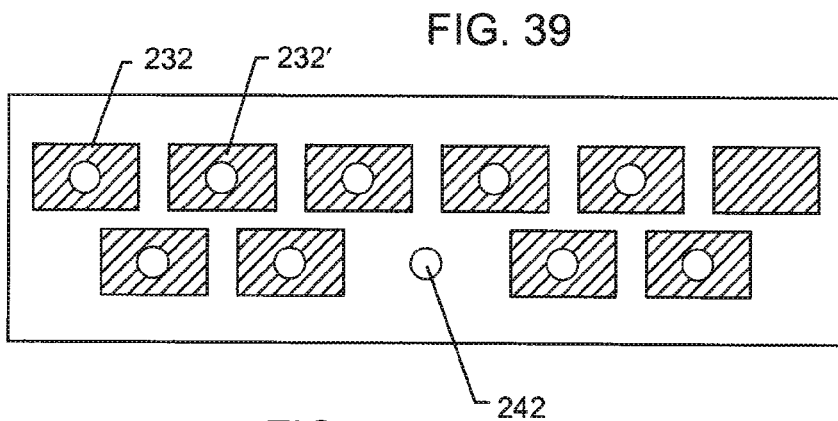
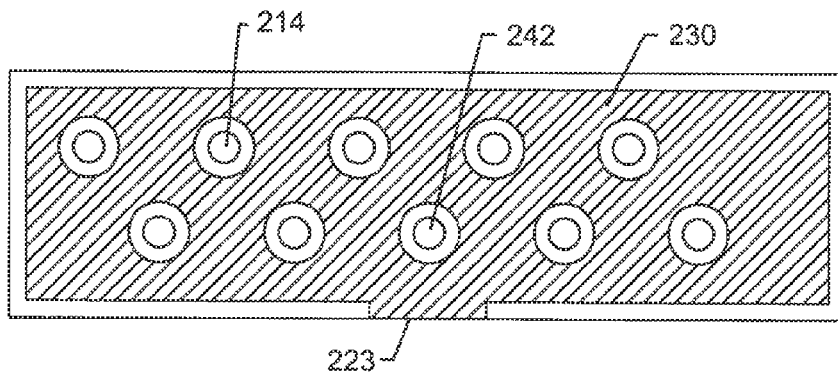
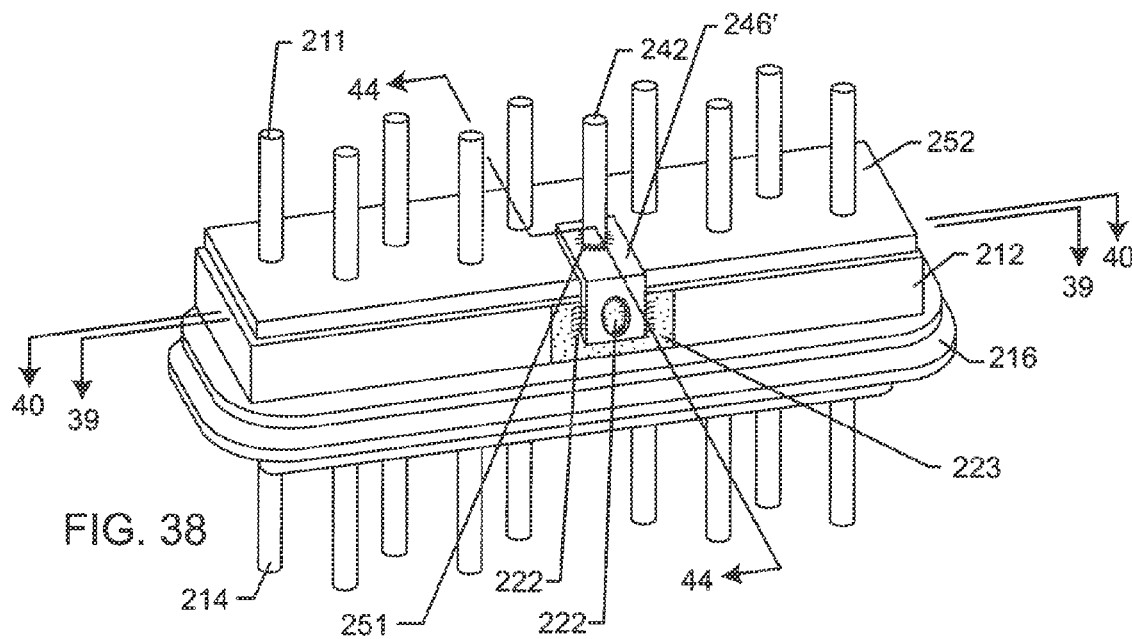
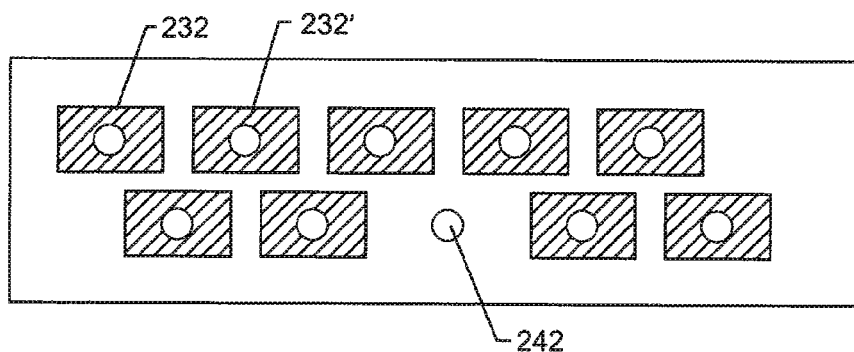
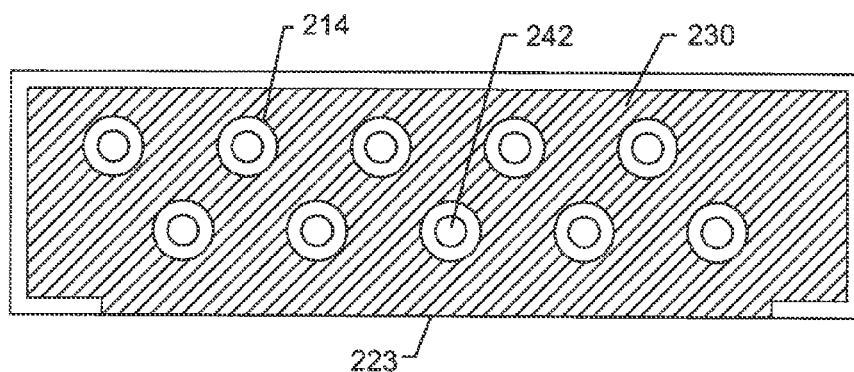
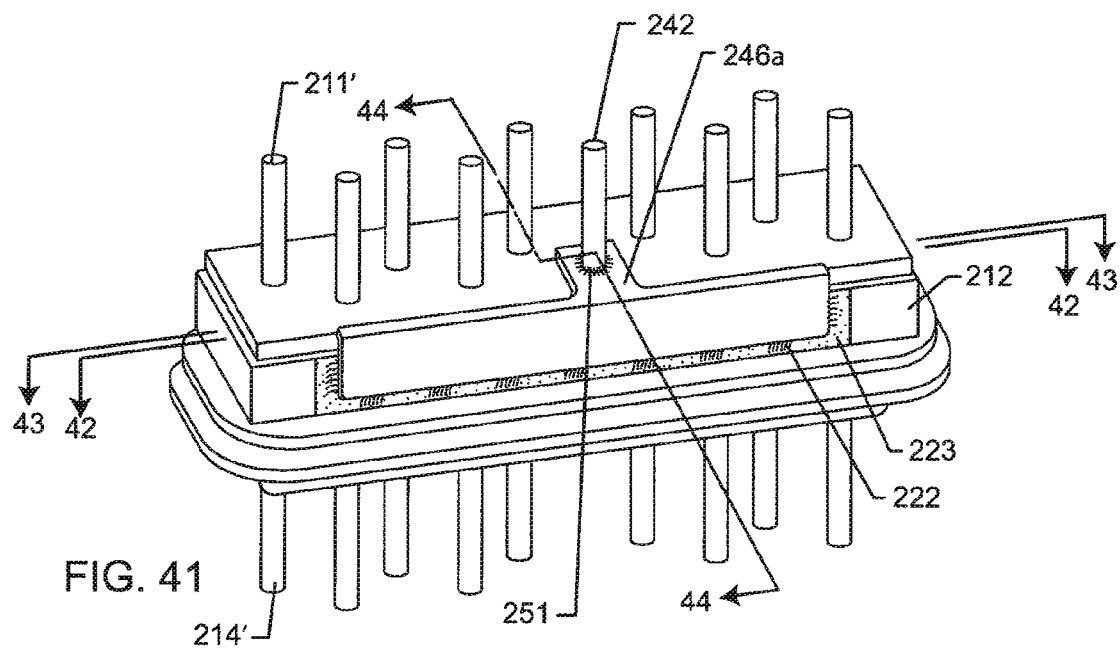


FIG. 37





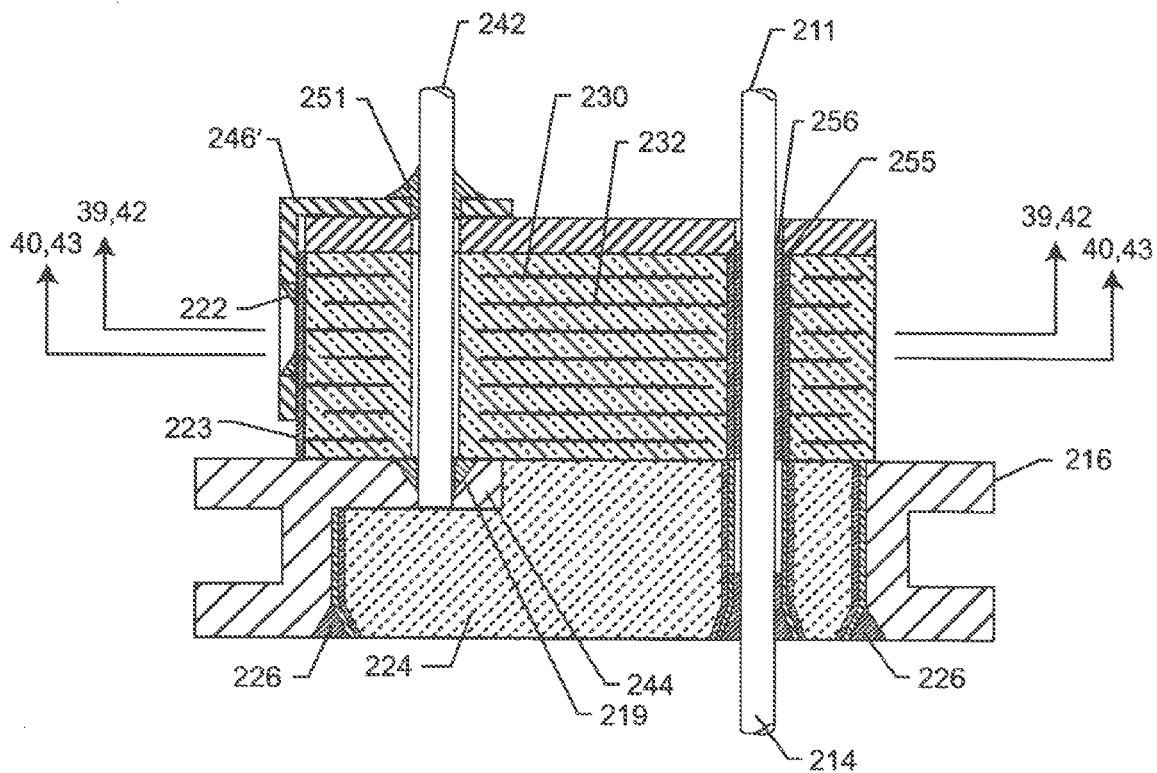


FIG. 44

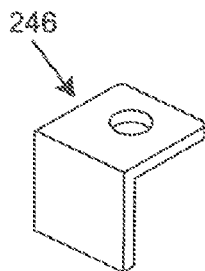


FIG. 45A

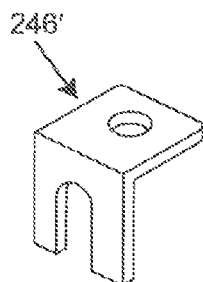


FIG. 45B

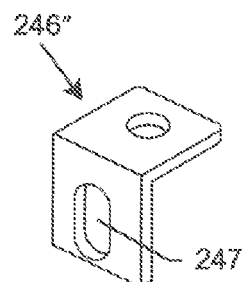


FIG. 45C

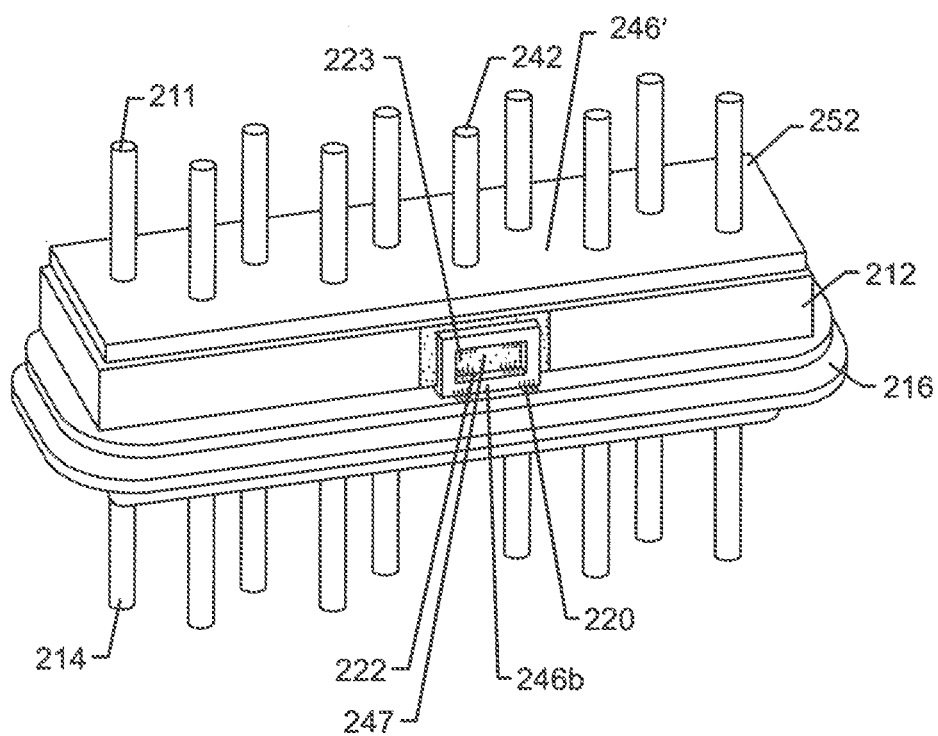


FIG. 46

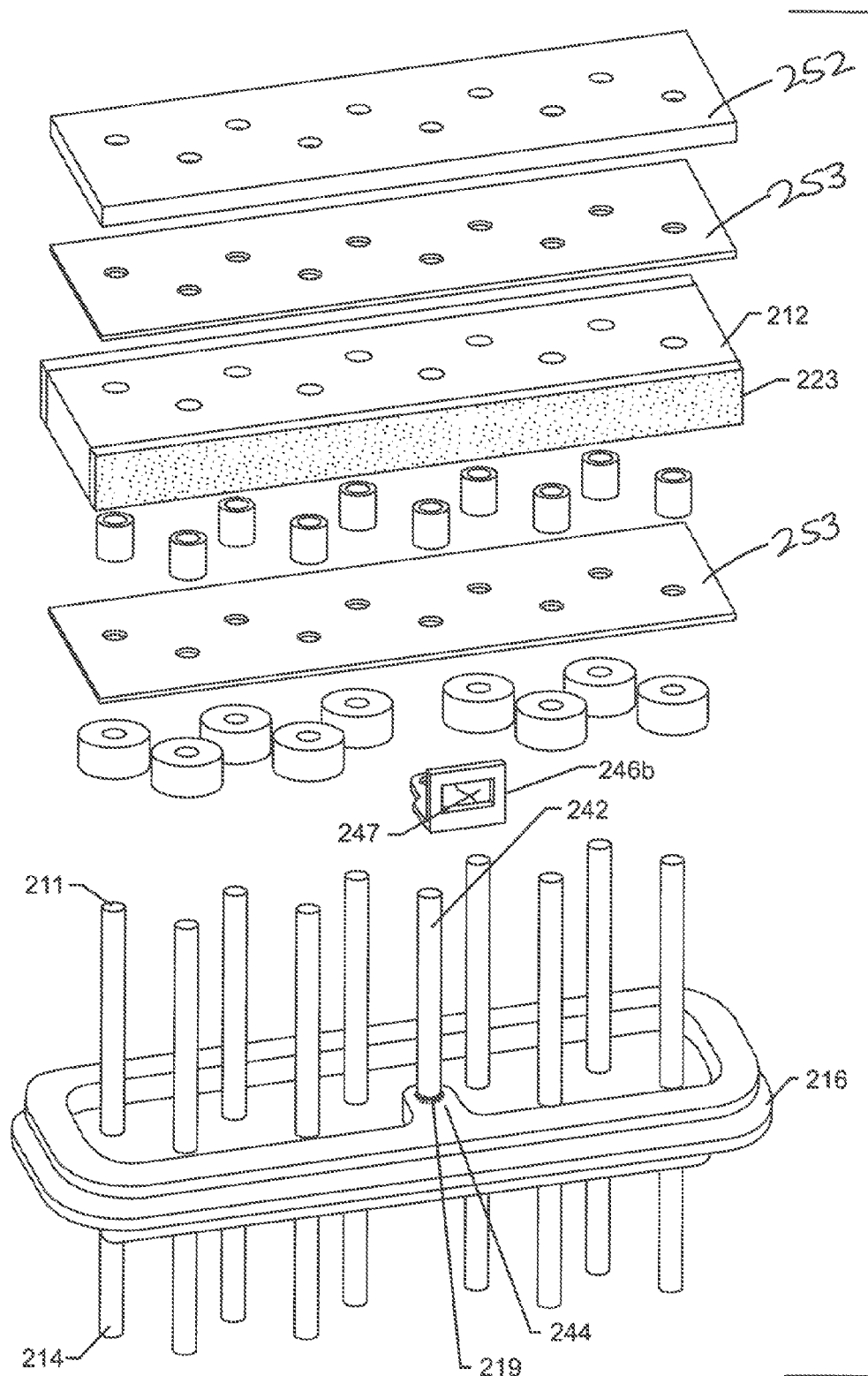
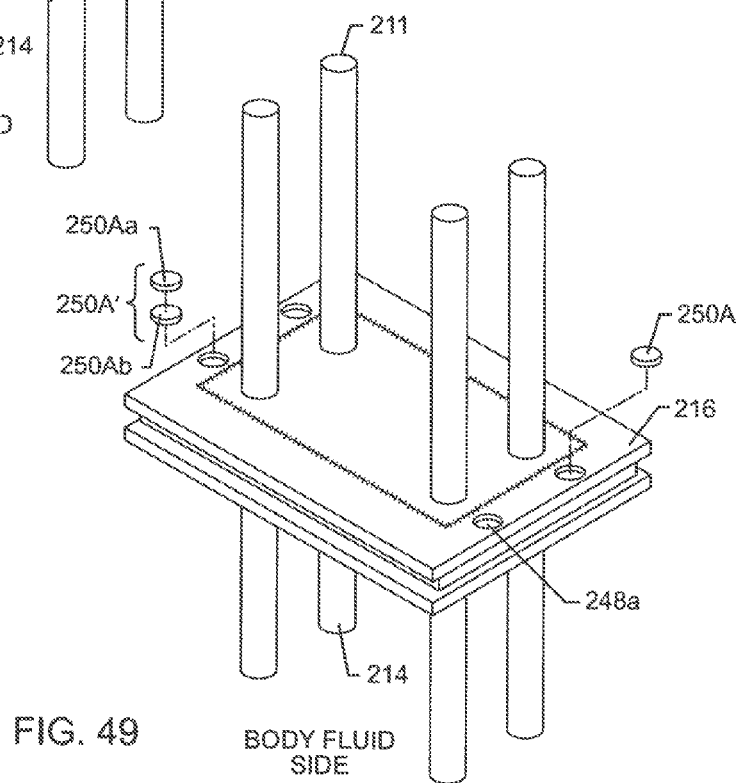
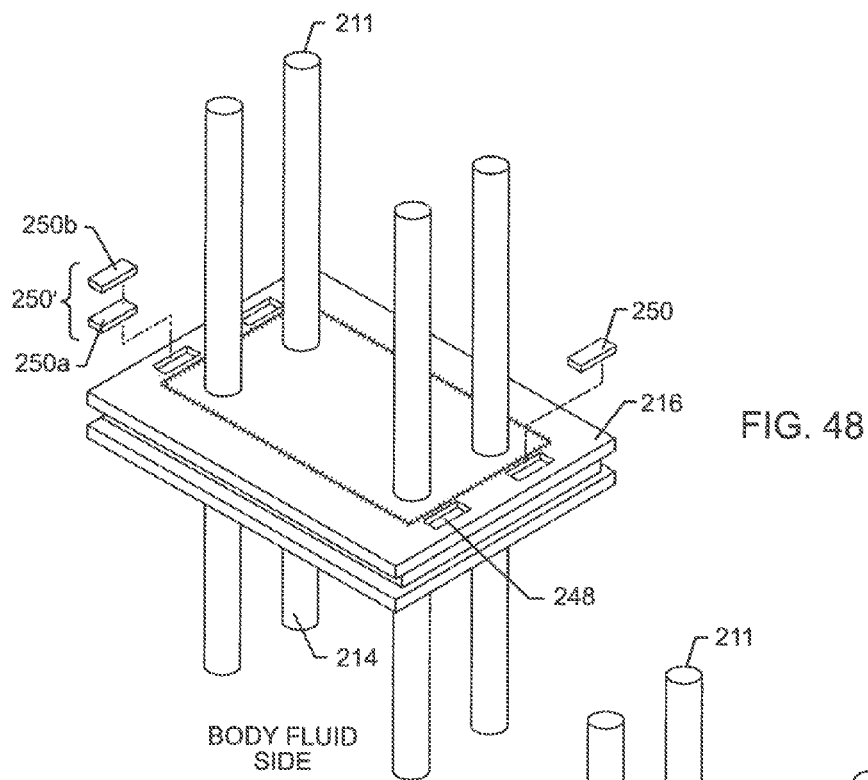


FIG. 47



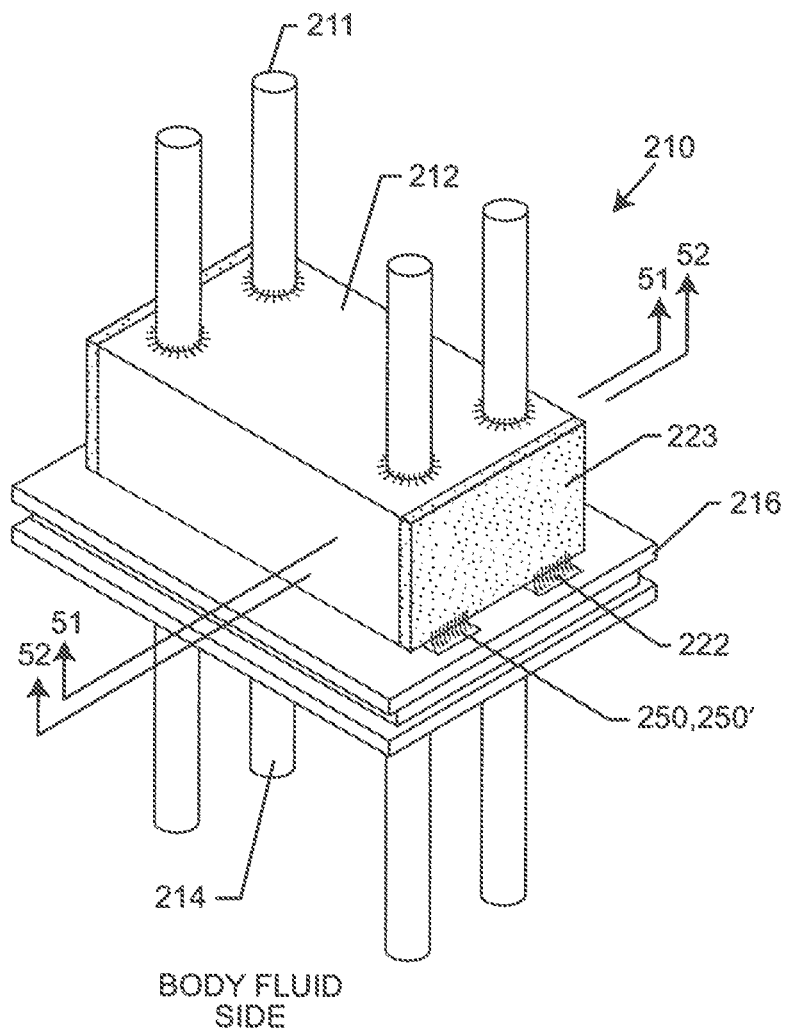


FIG. 50



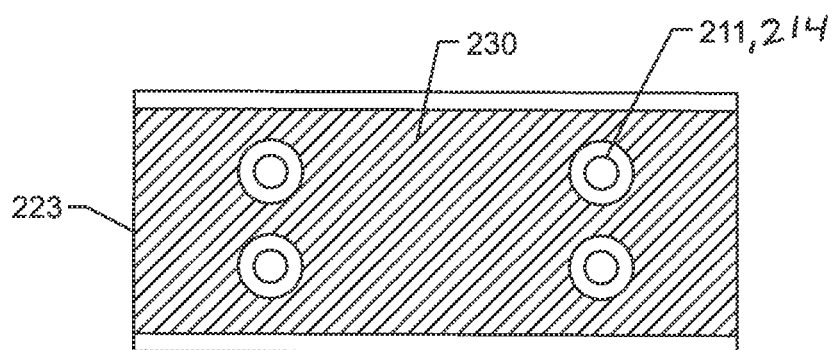


FIG. 51

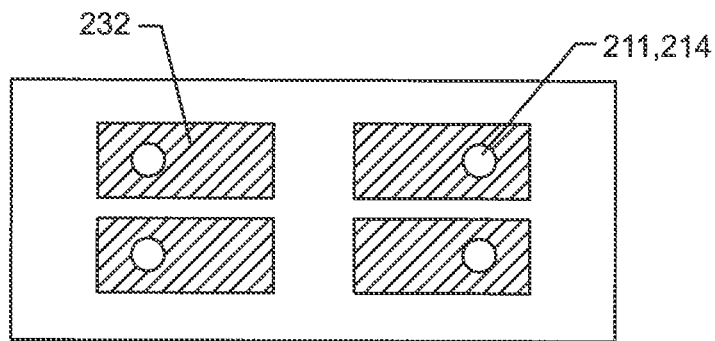


FIG. 52

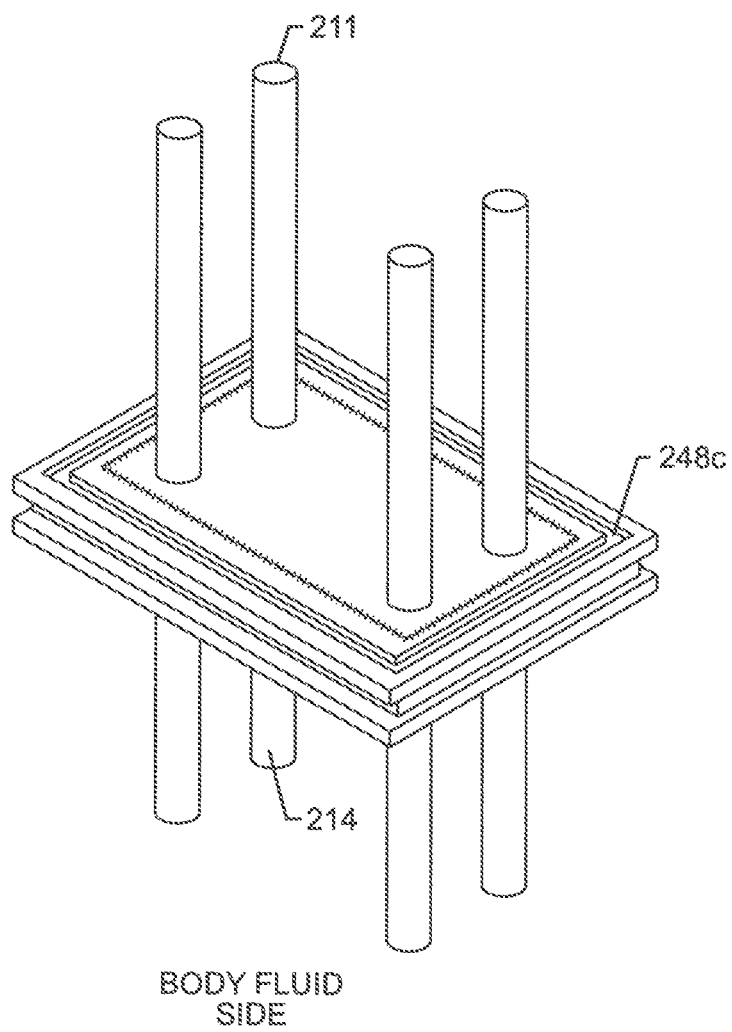
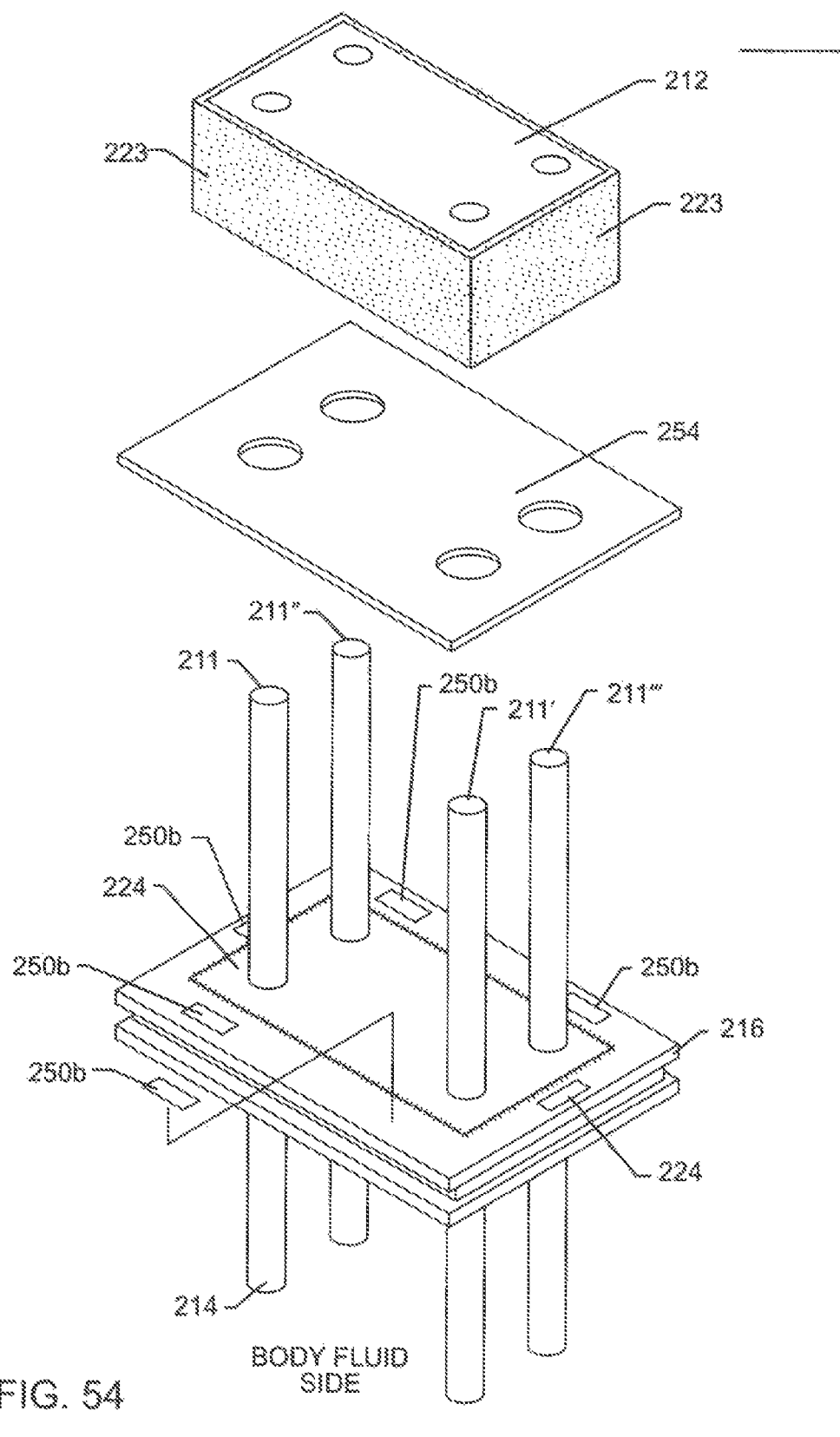


FIG. 53



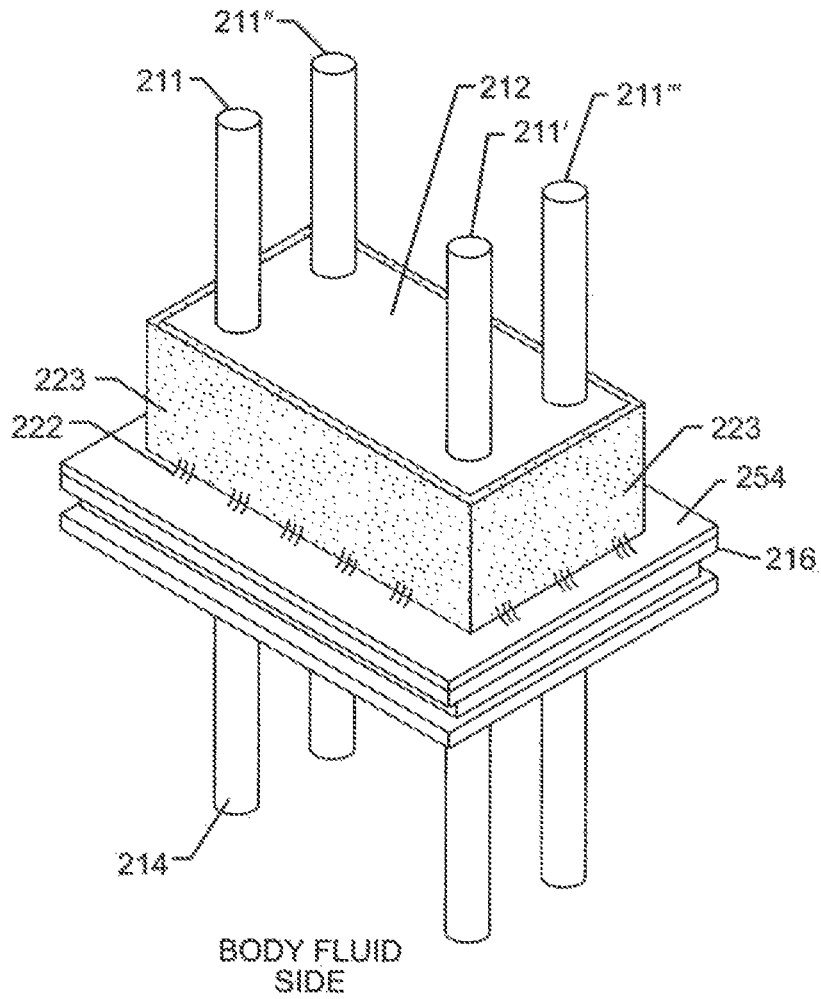
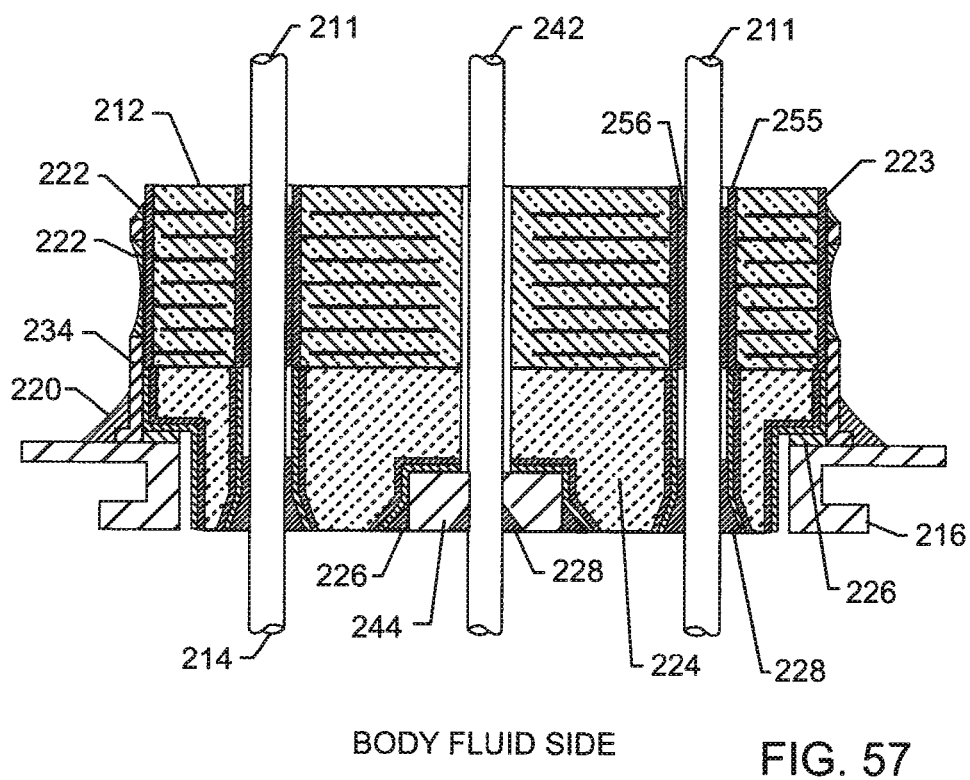
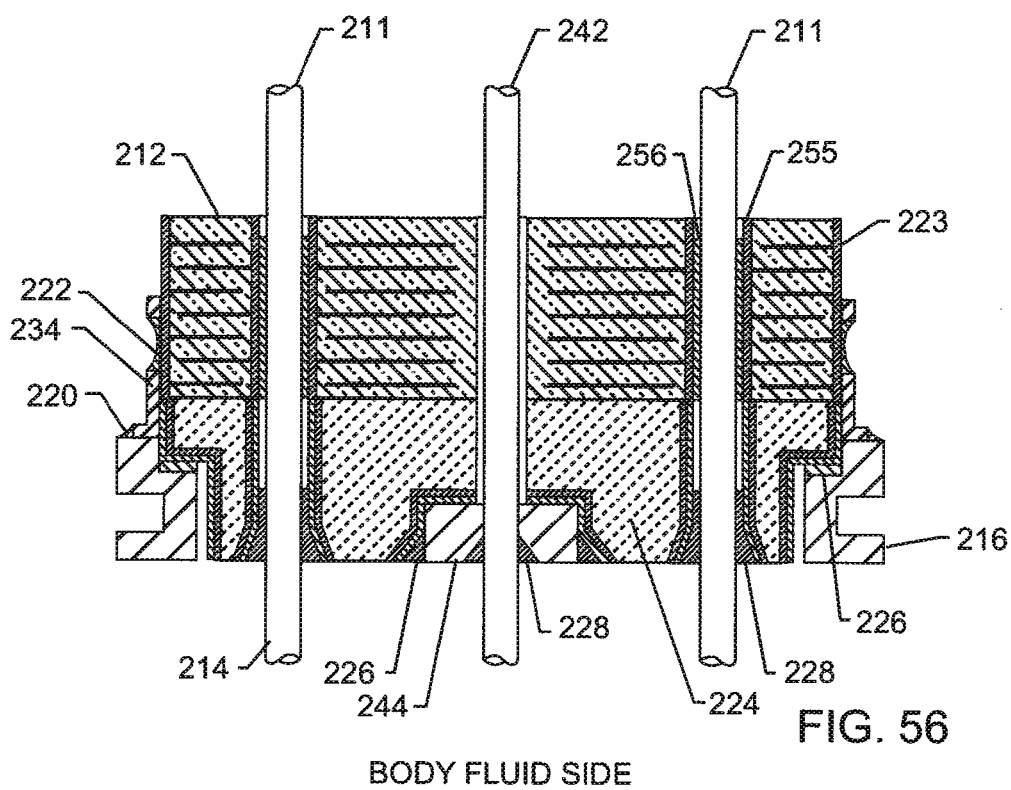
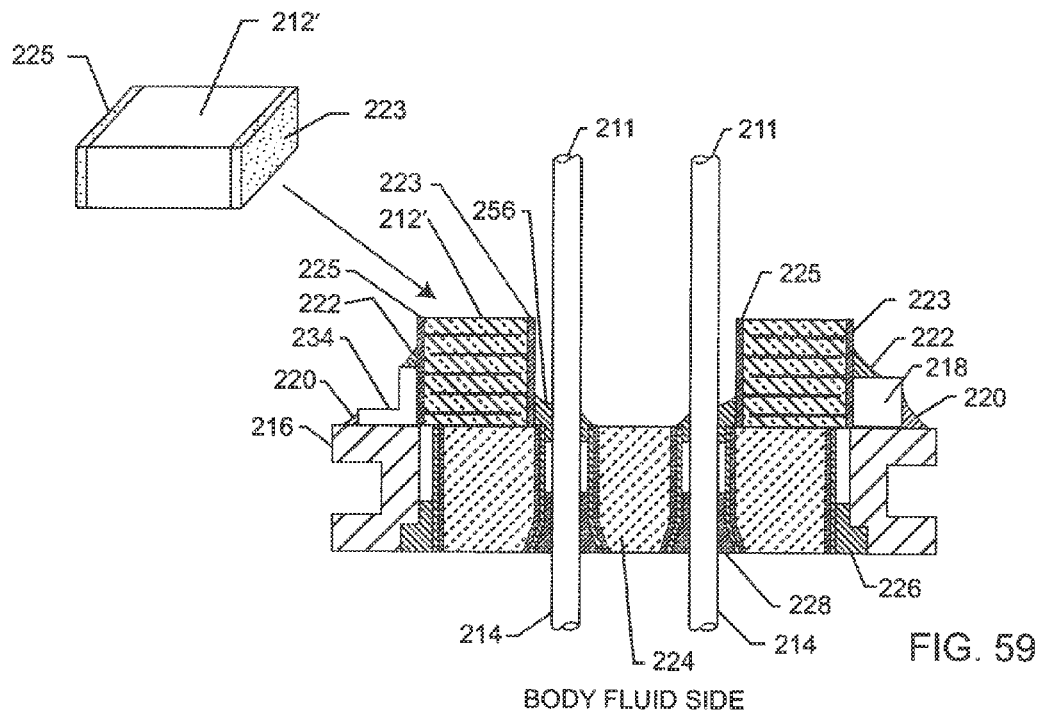
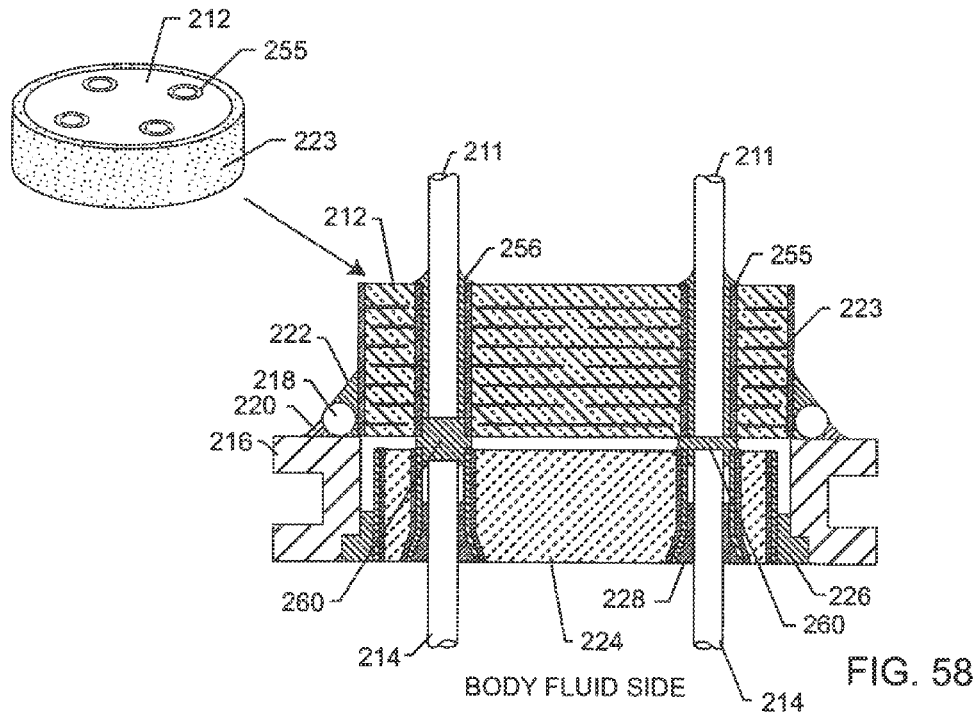
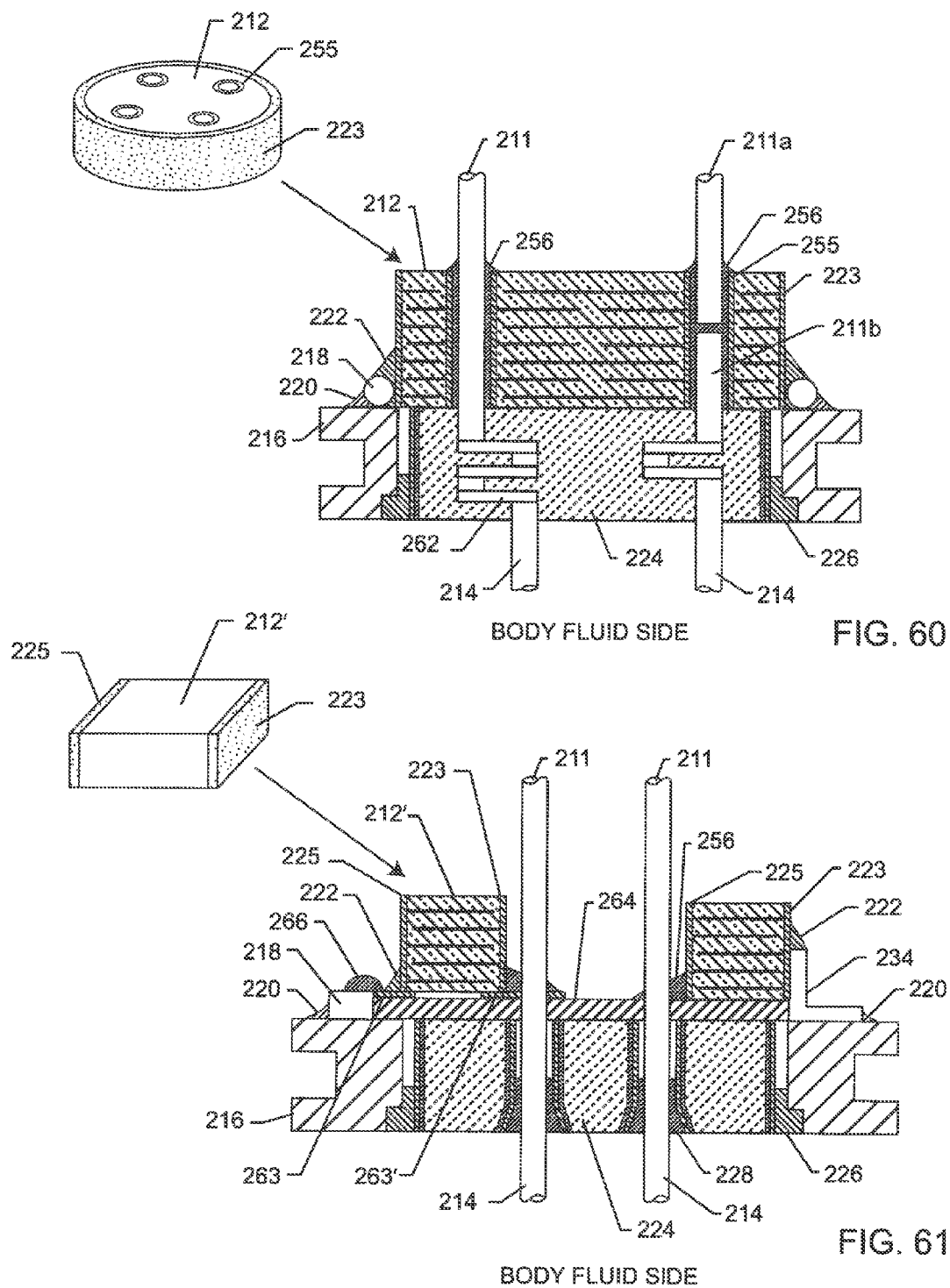


FIG. 55







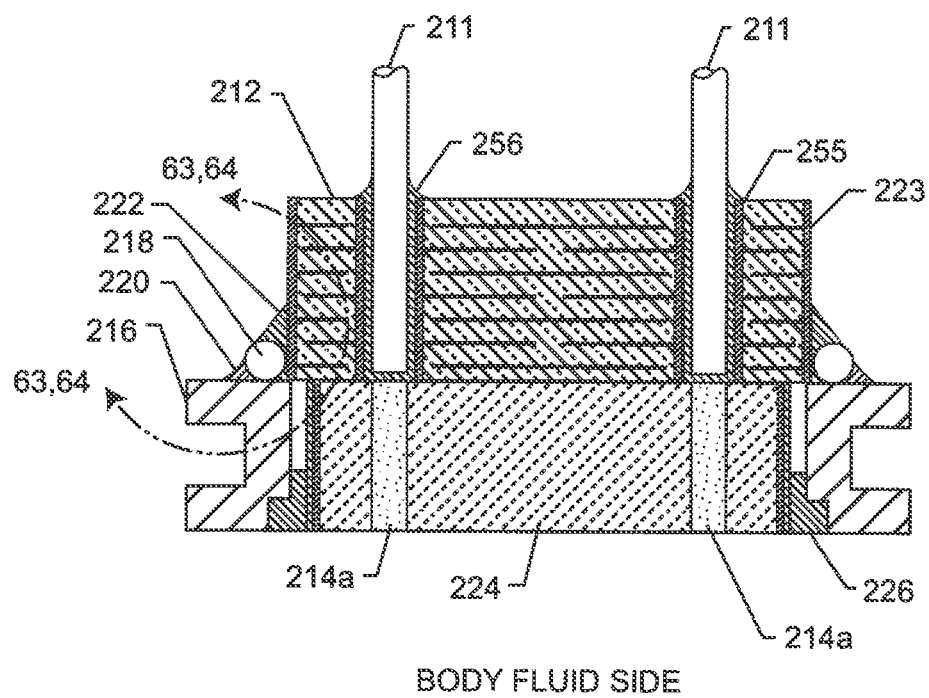


FIG. 62



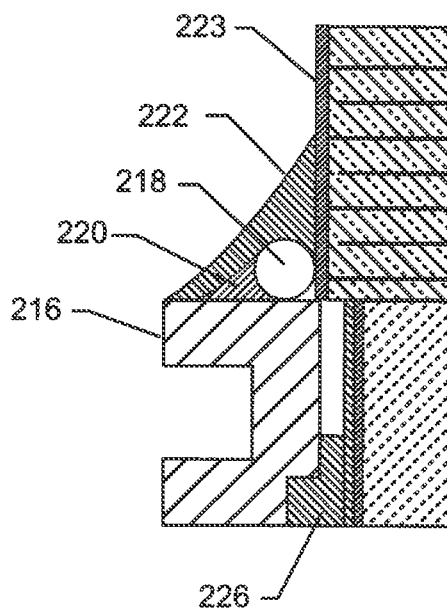


FIG. 63

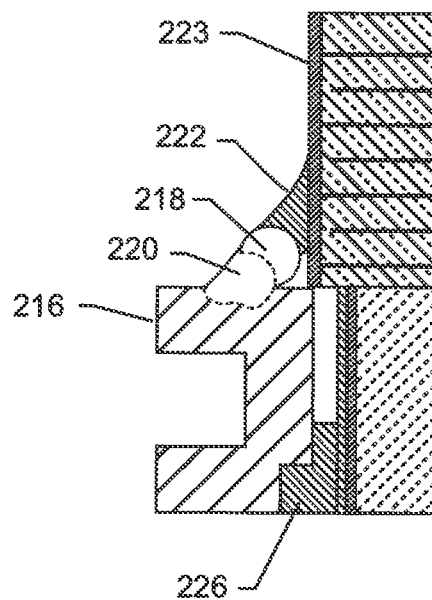


FIG. 64

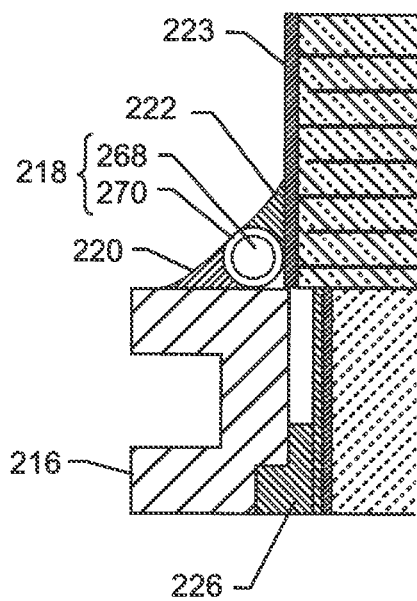


FIG. 65

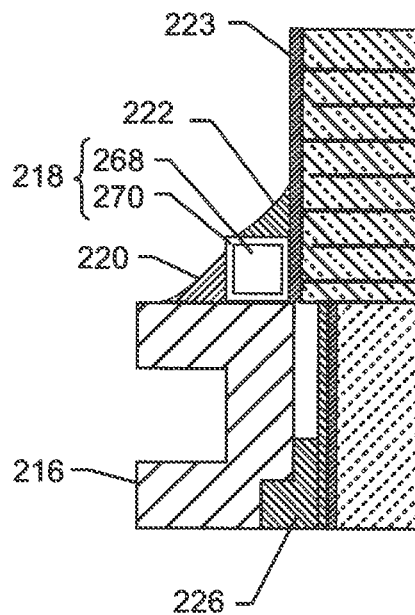


FIG. 66

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# LOW IMPEDANCE OXIDE RESISTANT GROUNDED CAPACITOR FOR AN AIMD

## CROSS-REFERENCE TO RELATED APPLICATIONS

This continuation-in-part application claims priority to application Ser. No. 14/202,653, filed on Mar. 10, 2014, now U.S. Pat. No. 9,108,066, where Ser. No. 14/202,653 is a continuation-in-part application to application Ser. No. 13/873,832, filed on Apr. 30, 2013, now U.S. Pat. No. 8,868,189; where application Ser. No. 14/202,653 is a continuation-in-part application to application Ser. No. 13/743,276, filed on Jan. 16, 2013; and where application Ser. No. 14/202,653 claims the benefit of provisional application Ser. No. 61/841,419, filed on Jun. 30, 2013; the contents of all of these applications are fully incorporated herein with these references.

## DESCRIPTION

### 1. Field of the Invention

The present invention generally relates to feedthrough capacitors. More particularly, the present invention relates to a feedthrough capacitor located on the device side with a low impedance and oxide-resistant electrical connection.

### 2. Background of the Invention

Feedthrough capacitors and MLCC chip capacitors are well known in the prior art for active implantable medical devices (AIMDs). One is directed to U.S. Pat. Nos. 5,333,095; 5,905,627; 6,275,369; 6,529,103; and 6,765,780, all of which are incorporated herein by reference. The hermetic seal feedthrough terminal assemblies generally consist of a titanium ferrule into which an alumina hermetic seal is gold brazed. One or more leadwires penetrate through the alumina in non-conductive relationship with the ferrule. Gold brazes are also used to form a hermetic terminal between the one or more leadwires and the alumina ceramic.

First, some general information concerning good engineering design practice for electromagnetic interference (EMI) filters is instructive. It is very important to intercept the EMI at the point of lead conductor ingress and egress to the AIMD. It would be an inferior practice to put filtering elements down in the circuit board as this would draw EMI energy inside of the AIMD housing where it could re-radiate or cross-couple to sensitive AIMD circuits. A superior approach is to mount one or more feedthrough capacitor or MLCC-type capacitors right at the point of leadwire entrance so that the capacitor can couple to high frequency EMI signals from the lead conductors directly to the AIMD housing serving as an energy dissipating surface.

There are some interesting design challenges however. The titanium ferrule, which is laser welded into the AIMD housing, is at ground potential. Titanium tends to form oxides which act as either insulators or semi-conductor. Accordingly, grounding the feedthrough capacitor electrode plates directly to the titanium ferrule is contra-indicated. Reference is made to U.S. Pat. No. 6,465,779 (which is incorporated with this reference) which describes gold bond pad areas where the feedthrough capacitor external metallization can be directly connected to gold. The gold to which the feedthrough capacitor is directly connected is the braze material used to form the hermetic seal between the alumina and the titanium ferrule. As noted above, the hermetic seal is formed via a brazing process. By attaching the capacitor's ground plates to the gold, one can be assured that there will be no oxide that will increase the capacitor's equivalent

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series resistance (ESR) which can seriously degrade the capacitor's performance at high frequency. An undesirable aspect of using the gold braze for attachment is that gold is very expensive. Accordingly, there is a need for methods that provide a reliable low impedance ground path which are oxide resistant for grounding of AIMD filter capacitors. The present invention fulfills these needs and provides other related advantages.

## SUMMARY OF THE INVENTION

An exemplary embodiment of a hermetically sealed filtered feedthrough assembly for an active implantable medical device (AIMD), includes: a) an electrically conductive ferrule configured to be installed into an opening of a housing of the AIMD, the ferrule having a ferrule opening with an integrally formed, electrically conductive extension at least partially extending into the ferrule opening; b) an electrically non-conductive insulator, the insulator hermetically sealing the ferrule opening, wherein the insulator defines and separates a body fluid side from a device side; c) an electrically conductive pathway hermetically sealed and disposed through the insulator between the body fluid side and the device side, the pathway in electrically non-conductive relation to the ferrule; d) a filter capacitor located on the device side; e) a first low impedance electrical coupling between the first metallization and the pathway; f) a ground conductor disposed through the filter capacitor in non-conductive relation with the at least one active and ground electrode plates, where the ground conductor is electrically coupled to the extension of the ferrule; and g) an oxide-resistant metal addition disposed on the device side, the oxide-resistant metal addition electrically coupling the ground conductor to the second metallization of the filter capacitor. The filter capacitor includes: i) a capacitor dielectric; ii) a first metallization attached to the capacitor dielectric separate from a second metallization attached to the capacitor dielectric; iii) at least one active electrode plate and at least one ground electrode plate disposed within the capacitor dielectric; iv) wherein the at least one active electrode plate is disposed parallel to the at least one ground electrode plate; v) wherein the first metallization is electrically coupled with the at least one active electrode plate; vi) and wherein the second metallization is electrically coupled with the at least one ground electrode plate. Optionally not shown, the electrically conductive extension may also be separately machined or made and then physically attached to the ferrule through welding, bonding or the like, so that the extension may not need to be integrally formed at the same time of the ferrule as one continuous and uninterrupted part of the ferrule.

A grounding pathway may be defined on the device side going from the second metallization, through the oxide-resistant metal addition and to the extension of the ferrule.

The total resistance of the grounding pathway may be less than 5 milliohm. The total resistance of the grounding pathway may be less than 1 milliohm. The total inductance of the grounding pathway may be less than 10 nanohenries. The total inductance of the grounding pathway may be less than 1 nanohenries.

The oxide-resistant metal addition may be partially disposed between the insulator and the filter capacitor. The oxide-resistant metal addition may be partially disposed above a top surface of the filter capacitor, the top surface defined as facing away from the insulator.

An insulative sheet may be partially disposed between the top surface of the filter capacitor and the oxide-resistant

metal addition. An insulative sheet may be disposed between the filter capacitor and the insulator.

The oxide-resistant metal addition may be selected from the group consisting of an L-shaped pad and an L-shaped pad with cutouts.

The hermetically sealed filtered feedthrough assembly can include a first electrically conductive connection material, the first connection material electrically coupling the oxide-resistant metal addition to the ground conductor.

The hermetically sealed filtered feedthrough assembly can include a second electrically conductive connection material, the second connection material electrically coupling the oxide-resistant metal addition to the second metallization of the filter capacitor. The second electrically conductive connection material may include a plurality of connections electrically coupling the oxide-resistant metal addition to the second metallization of the filter capacitor.

The filter capacitor may be a feedthrough capacitor.

Another exemplary embodiment of a hermetically sealed filtered feedthrough assembly for an active implantable medical device includes: a) an electrically conductive ferrule configured to be installed into an opening of a housing of the AIMD, the ferrule having a ferrule opening with an integrally formed, electrically conductive extension at least partially extending into the ferrule opening; b) an electrically non-conductive insulator, the insulator hermetically sealing the ferrule opening, wherein the insulator defines and separates a body fluid side from a device side; c) an electrically conductive pathway hermetically sealed and disposed through the insulator between the body fluid side and the device side, the pathway in electrically non-conductive relation to the ferrule; d) a filter capacitor located on the device side; e) a first low impedance electrical coupling between the first metallization and the pathway; f) a ground conductor disposed through the filter capacitor in non-conductive relation with the at least one active and ground electrode plates, where the ground conductor is electrically coupled to the extension of the ferrule; g) an oxide-resistant metal addition disposed on the device side, the oxide-resistant metal addition electrically coupling the ground conductor to the second metallization of the filter capacitor; and h) wherein a grounding pathway is defined on the device side going from the second metallization, through the oxide-resistant metal addition and to the extension of the ferrule, wherein the total resistance of the grounding pathway is less than 5 milliohm and the total inductance of the grounding pathway is less than 10 nanohenries. The filter capacitor includes: i) a capacitor dielectric; ii) a first metallization attached to the capacitor dielectric separate from a second metallization attached to the capacitor dielectric; iii) at least one active electrode plate and at least one ground electrode plate disposed within the capacitor dielectric; iv) wherein the at least one active electrode plate is disposed parallel to the at least one ground electrode plate; v) wherein the first metallization is electrically coupled with the at least one active electrode plate; vi) and wherein the second metallization is electrically coupled with the at least one ground electrode plate.

Another exemplary embodiment of a hermetically sealed filtered feedthrough assembly for an active implantable medical device includes: a) an electrically conductive ferrule configured to be installed into an opening of a housing of the AIMD, the ferrule having a ferrule opening with an integrally formed, electrically conductive extension at least partially extending into the ferrule opening; b) an electrically non-conductive insulator, the insulator hermetically sealing the ferrule opening, wherein the insulator defines

and separates a body fluid side from a device side; c) an electrically conductive pathway hermetically sealed and disposed through the insulator between the body fluid side and the device side, the pathway in electrically non-conductive relation to the ferrule; d) a filter capacitor located on the device side; e) a first low impedance electrical coupling between the first metallization and the pathway; f) a ground conductor disposed through the filter capacitor in non-conductive relation with the at least one active and ground electrode plates, where the ground conductor is electrically coupled to the extension of the ferrule; g) an oxide-resistant metal addition disposed on the device side, the oxide-resistant metal addition electrically coupling the ground conductor to the second metallization of the filter capacitor; h) a first electrically conductive connection material, the first connection material electrically coupling the oxide-resistant metal addition to the ground conductor; i) a second electrically conductive connection material, the second connection material electrically coupling the oxide-resistant metal addition to the second metallization of the filter capacitor; and j) wherein a grounding pathway is defined on the device side going from the second metallization, through the second connection material, through the oxide-resistant metal addition, through the first connection material, through the ground conductor and to the extension of the ferrule, wherein the total resistance of the grounding pathway is less than 5 milliohm and the total inductance of the grounding pathway is less than 10 nanohenries. The filter capacitor includes: i) a capacitor dielectric; ii) a first metallization attached to the capacitor dielectric separate from a second metallization attached to the capacitor dielectric; iii) at least one active electrode plate and at least one ground electrode plate disposed within the capacitor dielectric; iv) wherein the at least one active electrode plate is disposed parallel to the at least one ground electrode plate; v) wherein the first metallization is electrically coupled with the at least one active electrode plate; vi) wherein the second metallization is electrically coupled with the at least one ground electrode plate;

Other features and advantages of the present invention will become apparent from the following more detailed description, when taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate the invention. In such drawings;

FIG. 1 illustrates a wire-formed diagram of a generic human body showing various types of active implantable and external medical devices currently in use;

FIG. 2 is an isometric cut-away view of a unipolar feedthrough capacitor;

FIG. 3 is a cross-sectional view of the unipolar capacitor of FIG. 2 shown connected to the hermetic terminal of an AIMD;

FIG. 4 is a schematic diagram of the unipolar feedthrough capacitor shown in FIGS. 2 and 3;

FIG. 5 is an exploded view of the cover sheets and internal electrodes of the unipolar capacitor previously described in FIGS. 2 and 3;

FIG. 6 is a diagrammatic perspective view of a typical AIMD;

FIG. 7 is an isometric view of the quad polar feedthrough capacitor previously described in the prior art pacemaker of FIG. 6;

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FIG. 8 is a sectional view taken from section 8-8 of FIG. 7 and illustrates the quad polar feedthrough capacitor interior electrode plates;

FIG. 9 is an exploded view of the quad polar feedthrough capacitor of FIG. 7;

FIG. 10 is the schematic diagram of the quad polar feedthrough capacitor of FIG. 7;

FIG. 11 illustrates a prior art quad polar feedthrough capacitor that is rectangular instead of round;

FIG. 12 is an isometric view of the feedthrough assembly before the feedthrough capacitor is placed on top;

FIG. 13 is taken from section 13-13 from FIG. 11 showing the four active electrode plates;

FIG. 14 is taken from section 14-14 from FIG. 11 and illustrates the ground electrode plate;

FIG. 15 is an assembly view taken from FIGS. 11-14 showing the quad polar rectangular feedthrough capacitor mounted onto the hermetic seal housing and the ferrule;

FIG. 16 is a sectional view taken from section 16-16 from FIG. 15 cutting through one of the leadwires;

FIG. 17 is the electrical schematic diagram of the quad polar feedthrough capacitors previously illustrated in FIGS. 14 and 15;

FIG. 18 is a perspective view showing gold bond pads used to eliminate the problem of attachment to oxides of titanium between the feedthrough capacitor outside diameter and its ground electrode plate sets;

FIG. 19 shows that the electrical connections between the capacitor's ground metallization is now directly connected to the oxide resistant noble pad;

FIG. 20 is a sectional view of the structure of FIG. 19 taken through lines 20-20;

FIG. 21 is very similar to FIG. 19, except that the quad polar capacitor is round which is consistent with the feedthrough capacitor previously illustrated in the cardiac pacemaker of FIG. 6;

FIG. 22 is generally taken from section 22-22 from FIG. 21 cutting through two leadwires and illustrates the capacitor's internal structure including its ground and active electrode plates;

FIG. 23 illustrates the electrical schematic diagram of the improved rectangular quad polar feedthrough capacitor of FIG. 19 and the round quad polar capacitor of FIG. 21;

FIG. 24 illustrates attenuation versus frequency comparing the ideal feedthrough capacitor to one that has undesirable ground electrode plate connection to an oxidized surface;

FIG. 25 is a perspective view of an exemplary feedthrough capacitor embodying the present invention;

FIG. 26 is a sectional view taken along line 26-26 of the structure of FIG. 25;

FIG. 27 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

FIG. 27A is an exploded view of the structure of FIG. 27 showing the peninsula portion of the ferrule;

FIG. 28 is a sectional view taken along line 28-28 of the structure of FIG. 27;

FIG. 28A is an enlarged view of a novel embodiment of a similar structure to FIG. 28 taken along lines 28A-28A;

FIG. 28B is another embodiment similar to the structure of FIG. 28A now showing a rectangular shaped structure attached to the ferrule;

FIG. 28C is a view similar to 27A except now showing a recess on the ferrule for the wire to fit within;

FIG. 29 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

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FIG. 30 is a sectional view taken along line 30-30 of the structure of FIG. 29 cutting through two leadwires;

FIG. 31 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

FIG. 32 is a sectional view taken along line 32-32 of the structure of FIG. 31 cutting through two leadwires;

FIG. 33 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

FIG. 34 is a sectional view taken along the non-linear line 34-34 of the structure of FIG. 33;

FIG. 35 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

FIG. 36 is an exploded view of the structure of FIG. 35 showing the peninsula portion of the ferrule;

FIG. 37 is a sectional view taken along line 37-37 of the structure of FIG. 35;

FIG. 38 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

FIG. 39 is a sectional view taken along line 39-39 of the structure of FIG. 38 now showing a ground electrode plate;

FIG. 40 is an sectional view taken along line 40-40 of the structure of FIG. 38 now showing an active electrode plate;

FIG. 41 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

FIG. 42 is an sectional view taken along line 42-42 of the structure of FIG. 41 now showing a ground electrode plate;

FIG. 43 is an sectional view taken along line 43-43 of the structure of FIG. 41 now showing an active electrode plate;

FIG. 44 is a sectional view taken along the non-linear lines 44-44 of the structures of both FIGS. 38 and 41;

FIGS. 45A, 45B and 45C are perspective views of various embodiments of the novel ground attachments shown in FIGS. 38, 41 and 44;

FIG. 46 is a perspective view of another exemplary feedthrough capacitor embodying the present invention;

FIG. 47 is an exploded view of the structure of FIG. 46 showing the novel ground attachment below the capacitor;

FIG. 48 is a perspective view of another exemplary feedthrough embodying the present invention now showing novel rectangular ground attachments in the ferrule;

FIG. 49 is a perspective view of another exemplary feedthrough embodying the present invention now showing novel circular ground attachments in the ferrule;

FIG. 50 is similar to either FIG. 48 or 49 now showing the capacitor grounded to the ferrule;

FIG. 51 is a sectional view taken along line 51-51 of the structure of FIG. 50 now showing a ground electrode plate;

FIG. 52 is a sectional view taken along line 52-52 of the structure of FIG. 50 now showing an active electrode plate;

FIG. 53 is a perspective view of another exemplary feedthrough embodying the present invention now showing novel ground attachments around the continuous perimeter of the ferrule;

FIG. 54 is an exploded view of another exemplary feedthrough capacitor embodying the present invention now showing novel ground attachment plate;

FIG. 55 is the perspective assembled view of the structure of FIG. 54 showing the capacitor metallization grounded to the novel plate;

FIG. 56 is a sectional view similar to FIG. 28 showing an alternative hermetic seal between the ferrule and the insulator;

FIG. 57 is a sectional view similar to FIG. 28 showing another alternative hermetic seal between the ferrule and the insulator;

FIG. 58 is a sectional view similar to FIG. 26 showing discontinuous leadwires;

FIG. 59 is a sectional view similar to FIG. 68 now showing MLCC chip capacitors instead of feedthrough capacitors;

FIG. 60 is a sectional view similar to FIG. 58 now showing no gold brazes between the alumina insulator and the corresponding leads but rather a co-fired alumina ceramic;

FIG. 61 is a sectional view similar to FIG. 59 now with a substrate or circuit board;

FIG. 62 is a sectional view similar to FIG. 58 now showing a co-fired alumina ceramic insulator with solid filled vias;

FIG. 63 is an enlarged sectional view taken from section 63-63 from FIG. 62 showing human or robotic manufacturing;

FIG. 64 is an enlarged sectional view taken from section 64-64 from FIG. 62 showing a laser-welded metallurgical bond;

FIG. 65 is an enlarged sectional view similar to section 63-63 now showing a circular clad wire; and

FIG. 66 is an enlarged sectional view similar to section 63-63 now showing a square clad wire.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a wire-formed diagram of a generic human body showing various types of active implantable and external medical devices 100 that are currently in use. 100A is a family of external and implantable hearing devices which can include the group of hearing aids, cochlear implants, piezoelectric sound bridge transducers and the like. 100B includes an entire variety of neurostimulators and brain stimulators. Neurostimulators are used to stimulate the Vagus nerve, for example, to treat epilepsy, obesity and depression. Brain stimulators are similar to a pacemaker-like device and include electrodes implanted deep into the brain for example but not limited to sensing the onset of the seizure and also providing electrical stimulation to brain tissue to prevent the seizure from actually happening, or for treating memory loss, Alzheimer's and the like. The leadwires that come from a deep brain stimulator are often placed using real time imaging. Most commonly such leadwires are placed during real time MRI. 100C shows a cardiac pacemaker which is well-known in the art. 100D includes the family of left ventricular assist devices (LVAD's), and artificial hearts, including the recently introduced artificial heart known as the ABIOCOR. 100E includes an entire family of drug pumps which can be used for dispensing of insulin, chemotherapy drugs, pain medications and the like. Insulin pumps are evolving from passive devices to ones that have sensors and closed loop systems. That is, real time monitoring of blood sugar levels will occur. These devices tend to be more sensitive to EMI than passive pumps that have no sense circuitry or externally implanted leadwires. 100F includes a variety of external or implantable bone growth stimulators for rapid healing of fractures. 100G includes urinary incontinence devices. 100H includes the family of pain relief spinal cord stimulators and anti-tremor stimulators, 100H also includes an entire family of other types of neurostimulators used to block pain. 100I includes a family of implantable cardioverter defibrillators (ICD) devices and also includes the family of congestive heart failure devices (CHF). This is also known in the art as cardio resynchronization therapy devices, otherwise known as CRT devices. 100J illustrates an externally worn pack. This pack could be an external insulin pump, an external

drug pump, an external neurostimulator, a Holter monitor with skin electrodes or even a ventricular assist device power pack.

FIG. 2 is an isometric cut-away view of a unipolar feedthrough capacitor 132. It has an outside diameter metallization 142 and an inside diameter metallization 144. Active electrode plates 148 and ground electrode plates 146 are interleaved in the dielectric body. As can be seen, the active and ground electrode plates are generally parallel to one another. The active electrode plate set 148 is connected to the inside diameter metallization 144. The ground electrode plate set 146 is connected to the outside diameter metallization 142. Metallization surfaces 142 and 144 can be glass fritted platinum silver or various types of plating. The metallization surfaces 142 and 144 are very important as it is easy to make electrical connection of these surfaces to other circuit elements.

FIG. 3 is a cross-sectional view of the unipolar capacitor of FIG. 2 shown connected to the hermetic terminal of an active implantable medical device, such as a cardiac pacemaker. Shown is a hermetic seal formed from an insulator 160, such as an alumina ceramic, glass or the like. A gold braze 162 forms a hermetic seal between the insulator 160 and leadwire 114, 111. The leadwire labeled 114 on the body fluid side is generally directed to an implantable lead that has an electrode contactable to biological cells (not shown). And there is a second gold braze 150 which hermetically connects the outside diameter of the insulator material 160 to a ferrule 112. To help form a hermetic seal between the insulator 160 and the leadwire 114 or ferrule 112, an adhesion layer 153 and a wetting layer 151 are used. Not shown is a typical first operation wherein the alumina ceramic 160 is first prepared by sputtering typically with a layer of molybdenum and then a layer of titanium. The first layer of molybdenum is the adhesion layer 153 and the second layer of titanium is the wetting layer 151 which provides for good wetting of the gold braze 162 or 150 to form the hermetic seal. In the prior art, the ferrule is generally of titanium. The AIMD housing 116 is also generally of titanium. The housing 116 also serves as an electrical ground represented by the ground symbol. A laser weld 154 is formed which connects the ferrule 112 to the AIMD housing 116 electrically and mechanically (physically). The laser weld 154 also forms a hermetic seal. The unipolar feedthrough capacitor 132 of FIG. 2 is shown mounted directly to the hermetic seal insulator. An electrical connection 156 connects the capacitor inside diameter metallization 144 to leadwire 111. There is also an electrical connection material 152 connected directly to the ferrule 112 as shown. This electrical connection 152 is substantially inferior to the present invention and thus undesirable. As shown, an electrical connection is being made directly to the titanium surface 112. It is well known that titanium, particularly when brought to elevated temperatures, forms oxides. Oxides of titanium, for example, titanium dioxide is so stable, it is used as a paint pigment. It is also highly resistive and has semi-conductive properties. For this reason, this titanium dioxide creates an undesirable series resistance  $R_{OXIDE}$  between the feedthrough capacitor and the ferrule 112 and/or AIMD housing 116.

FIG. 4 is a schematic diagram of unipolar feedthrough capacitor shown in FIGS. 2 and 3. Shown is an ideal feedthrough capacitor C. In general, feedthrough capacitors are three-terminal devices in that there is an input side 114 (terminal one), an output side 111 (terminal two) and a ground 116 (terminal three). It is well known that an implanted lead can undesirably act as an antenna and couple

to high frequency electromagnetic interference (EMI) energy. This EMI energy may be undesirably coupled along the implanted leadwire conductors to lead **111**, which is directed to sensitive AIMD electronics. It is well known that EMI can disrupt the proper operation of AIMD electronic circuitry. For example, there have been a number of case reports of complete inhibition of cardiac pacemakers when EMI was falsely detected as a normal cardiac rhythm and the pacemaker inhibited. This is immediately life-threatening as it leaves a pacemaker dependent patient without a heartbeat during the entire time of the EMI exposure. The feature in the feedthrough capacitor as illustrated in FIGS. **2** and **3** is to divert incoming EMI energy in the implanted lead and dissipate it to the electromagnetically shielded housing **116** of the AIMD which said EMI energy may be dissipated as a harmless amount of thermal or RF energy. In other words, it is the job of feedthrough capacitors to protect the sensitive AIMD electronics while at the same time freely allowing pacing or therapeutic pulses to pass and also to allow the AIMD to sense biological signals that are generally in the frequency range from zero to 2000 Hz without interruption. The capacitor is also known as a frequency variable impedance element. The capacitive reactance  $X_C$  in ohms is given by the equation:

$$X_C = 1/[2\pi fC]$$

wherein,  $f$ =frequency in hertz and  $C$ =the capacitance in farads. This inverse relationship with frequency means that, at very low frequencies, the capacitor looks like an open circuit (as if it were not there at all), and at very high frequencies, the capacitor acts as a short circuit where it diverts undesirable RF energy such as emissions from cellular telephones, microwave ovens or the like.

Referring once again to FIG. **4**, one can see  $R_{OXIDE}$ . This resistive element is highly undesirable because it degrades the performance of the feedthrough capacitor all across its frequency range. There is also a great deal of variability in this oxide. During the gold brazing operation or during the formation of the hermetic seal, oxide poisoning may reach any corner or part of the brazing oven. The inventors have experienced some of the parts to be relatively oxide free where others in the lot may have a very thick or heavy oxide build-up.

FIG. **5** is an exploded view of the cover sheets **147** and internal electrodes of the unipolar capacitor **132** previously described in FIGS. **2** and **3**. One can see that there are active electrode plates **148** screened onto dielectric layers **149** and interleaved with ground electrode plates **146**. A number of blank cover sheets **147** are placed on top and bottom for insulative and mechanical strength purposes.

FIG. **6** is a diagrammatic explosion of a typical AIMD, such as a cardiac pacemaker **100C**. It has an overall electromagnetic shielded titanium housing **116** along with a polymer header block (connector block) **101**. Shown, are two implantable leads **107** and **107'**, which in this case are directed to chambers of the heart **124**. There are additional electrodes located at point **109** in the right ventricle and distal electrode **109'** located in the right atrium. In the art, this is known as a simple dual chamber bipolar pacemaker. As shown, EMI can be undesirably coupled to leads **107** and **107'** where it can be conductive to the leadwires **114** of the hermetic seal assembly **120**. The feedthrough capacitor element **132** diverts the EMI conducted on leads **114** into the conductive AIMD housing **116** where it is dissipated as eddy currents or RF energy (EMI) coupled to surrounding body tissues. In any event, the EMI is prevented from reaching the delicate AIMD circuit boards **122**. The leads **107**, **107'** have

male connectors **105**, **105'** which are inserted into female connectors **103**, **103'** of the header block **101**.

FIG. **7** is an isometric view of the quad polar feedthrough capacitor **132** previously described in the prior art pacemaker of FIG. **6**. The quad polar feedthrough capacitor has an outside diameter metallization **142** and four feedthrough holes all of which have inside diameter metallization **144**.

FIG. **8** is a sectional view taken from section **8-8** of FIG. **7** and illustrates the quad polar feedthrough capacitor interior electrode plates. There is a ground electrode plate set **146** which is coupled to the outside diameter metallization **142**. There are four different sets of active electrode plates **148** which are each coupled to their own individual feedthrough hole **134**.

FIG. **9** is an exploded view of the quad polar feedthrough capacitor of FIG. **7**. Shown, are the four active electrode plate areas **148** and the ground electrode plates **146**. As previously described, these active and ground electrode plates are in interleaved relationship. There are also a number of blank ceramic cover sheets **147** added on top and bottom for mechanical strength and electrical insulation. Those skilled in the capacitor art will understand that a higher voltage capacitor could be built by interleaving additional blank electrodes between the active and ground electrode plates thereby building up the dielectric thickness. Typically, the dielectric material could be of barium titanate ceramic and could vary in dielectric constant  $k$  anywhere from 50 all the way up to several thousand.

FIG. **10** is the schematic diagram of the quad polar feedthrough capacitor of FIG. **6**. Again, as previously described for the unipolar capacitor of FIG. **2** and FIG. **4**, there is an undesirable resistance  $R_{OXIDE}$  as shown. Ideally, feedthrough capacitors are three-terminal devices that have no series inductance or series resistance in their ground connection. This is why they make such effective broadband electromagnetic interference filters. In general, a feedthrough capacitor can provide attenuation over a very broad frequency range extending even to 18 to 20 GHz. However, this oxide is highly undesirable as it can seriously degrade filter performance. In general, filter performance is described by the terms insertion loss or by attenuation. Both of these are generally measured in a balanced 50 ohm system with the measurement units in decibels.

FIG. **11** illustrates a prior art quad polar feedthrough capacitor that, in this case, is rectangular instead of round. It still has an outside metallization **142**, but in this embodiment, instead of being all around a perimeter or outside diameter, it is shown only over a portion of the rectangular edge of the capacitor. In another embodiment (not shown) the outside metallization **142** could extend around the entire perimeter of the capacitor. Feedthrough metallization **144** is provided for each of the four feedthrough holes. FIG. **11** in combination with FIG. **12** illustrates an exploded assembly view wherein the capacitor of FIG. **11** is designed to be mounted atop a prior art quad polar hermetic terminal of FIG. **12**. The hermetic terminal of FIG. **12** has four leadwires **111**, **114**, a hermetic insulator **124** and a ferrule **112**, generally of titanium. There is a gold braze **150** which forms a hermetic joint between the ferrule **112** and the generally alumina ceramic insulator **124**. There are four more gold brazes **162** which join leadwire **111** to the inside diameter holes of the hermetic insulator **124**.

FIG. **13** is taken from section **13-13** from FIG. **11**. Shown are the four active electrode plates **148** of the feedthrough capacitor.

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FIG. 14 is taken from section 14-14 from FIG. 11 and illustrates the ground electrode plate 146 of the feedthrough capacitor.

FIG. 15 is an assembly view taken from FIGS. 11 and 12 showing the quad polar rectangular feedthrough capacitor mounted onto the hermetic seal housing and the ferrule 112. An electrical connection 152 is generally made with a thermal-setting conductive adhesive between the capacitor metallization 142 directly to the ferrule 112.

FIG. 16 is a sectional view taken from section 16-16 from FIG. 15. This sectional view goes through one of the leadwires 111 and shows the interior ground electrode plate set 146 and the active electrode plate set 148. The ground electrode plates 146 make electrical and mechanical contact to the capacitor ground metallization 142. There is an electrical connection 152 shown directly to the top surface of the titanium ferrule 112. There is a cross-hatched area 164 which shows the formation of a very undesirable layer of titanium oxides. For simplicity, this layer is shown only on the top surface, but in reality, it would coat all of the surfaces of the titanium cross-section. As previously mentioned, the formation of this oxide can happen during initial gold brazing, during subsequent storage and handling of the overall filter feedthrough subassembly, or during laser welding of the ferrule 112 into the AIMD housing 116. One particular problem is that the thermal-setting conductive adhesive 152 contains a certain amount of available oxygen. When a laser weld is formed to the AIMD housing, which is positioned in slot 163, this significantly raises the temperature of thermal-setting conductive adhesive 152. That is why a thermal-setting conductive polyimide is the connection material of choice, as a conductive polyimide is stable at temperatures well above 300 degrees C. This is in comparison to most epoxies which are only rated to about 230 degrees C. When the temperature of this assembly is raised through laser welding to a relatively high temperature, oxygen can be released from a thermal-setting conductive material 152 and then form as a titanium dioxide or trioxide 164 on the ferrule 112 of the hermetic seal.

FIG. 17 is the schematic diagram of the quad polar feedthrough capacitors previously illustrated in FIGS. 11, 15 and 16. The undesirable  $R_{OXIDE}$  is shown in series between the ideal feedthrough capacitor and ground, which is the same electrical potential as the AIMD housing 116. As will be described in detail hereinafter, the presence of this resistive oxide seriously degrades the filter performance.

FIG. 18 is taken from FIG. 20 of U.S. Pat. No. 6,765,779 which describes gold bond pads to eliminate the problem of attachment to oxides of titanium between the feedthrough capacitor outside diameter and its ground electrode plate sets. Referring to FIG. 18, one can see that there are novel gold braze pads 165 that have been added. Referring to FIG. 12, one can see that these gold braze pads 165 are not present.

FIG. 19 shows that the electrical connections 152 between the capacitor's ground metallization 142 is now directly made to this non-oxidizable noble pad 165. U.S. Pat. No. 6,765,779 is incorporated herein by reference. As is shown in the '779 patent, one possible material for the oxide resistant pad 165 is gold. This gold pad 165 is continuous and is co-formed at the same time the hermetic seal (gold braze) is made to the alumina ceramic insulator 160. In fact, this is a limitation of U.S. Pat. No. 6,765,779 in that the gold bond pad 165 is always formed as part of the co-braze to the alumina ceramic insulator 160.

FIG. 20 is generally taken from section 20-20 from FIG. 19. It is very similar to FIG. 16 except that the gold braze

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area 165 has been enlarged to include the gold bond pad area 165. Pure gold has a high melting point (1064° C.) which is above the allotropic transformation temperature of titanium (883° C.). Titanium is soluble in gold, particularly more so at elevated temperature. Elevated temperature maximizes titanium dissolution into gold. As previously noted, titanium is highly reactive to air, readily forming surface oxides. Brazing to titanium, therefore, is generally performed at high vacuum. At high vacuum brazing temperatures, when a gold brazed joint 164 is formed between, for example, a gold braze preform and a titanium ferrule, the titanium reacts with the gold to form a direct metallurgical bond to the titanium ferrule 112. As this direct metallurgical bond is gold-rich, it essentially retains the high conductivity of the gold and its oxide resistant properties. In this regard, the enlarged gold braze surface area, that is, the bonding pad that is formed as part of the oxide-resistant metallurgical bond (oxide-resistant also remains oxide-free for the most part as any oxides that are formed are very minimal). This enlarged gold braze area serves as the electrical connection material that is connectable to the capacitor ground metallization 142. To summarize, a continuous electrical connection that is consistent in its conductivity over the service life of the device is made. The electrical connection is between the titanium ferrule 112 and the filter capacitor ground metallization 142 via the electrical connection material 152 directly to the non-oxidizable pad 165.

FIG. 21 is very similar to FIG. 19, except in this case, the quad polar capacitor is round which is consistent with the feedthrough capacitor 132 previously illustrated in the cardiac pacemaker of FIG. 6.

FIG. 22 is generally taken from section 22-22 from FIG. 21 and illustrates the capacitors internal structure including its ground and active electrode plates. Importantly, outside diameter electrical connection material 152, which connects the outside diameter metallization 142 to the ferrule 112, is directly attached to the gold braze material 165. The fact that some of this overlaps onto the titanium surface is not important. What is critical is that a suitable amount of the electrical connection material 152 is directly attached to an oxide resistant noble surface, so that an undesirable resistance can never develop.

FIG. 23 illustrates the schematic diagram of the improved rectangular quad polar feedthrough capacitor of FIG. 19 and the round quad polar capacitor of FIG. 21. One can see that there is insignificant resistance in the connection from the feedthrough capacitor to ground 116, which is the overall shielded equipotential surface of the electromagnetically shielded housing 116.

FIG. 24 is a graph of attenuation versus frequency curves. This graph compares the ideal feedthrough capacitor to one that has undesirable ground electrode plate connection to an oxidized surface. One can see that the feedthrough capacitor with the resistive oxide  $R_{OXIDE}$  has greatly reduced attenuation all across the frequency band as compared to the ideal feedthrough capacitor.

FIG. 25 illustrates an embodiment of a filtered feedthrough assembly of the present invention 210. Illustrated is a ferrule 216 of the hermetic seal. The ferrule 216 is generally of titanium. In this case, it has a continuous slot 217, which receives the can halves of an active implantable medical device, such as a cardiac pacemaker. These titanium can halves are then laser welded to the titanium ferrule 216. In general, a feedthrough capacitor 212 would be oriented towards the inside of the can to protect it from body fluids. In this case, there are novel round platinum iridium wires 218 as an oxide resistant metal addition, which have been



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laser welded **220** directly to the ferrule **216**. Laser weld **220** could also be replaced by a resistance weld or a secondary braze operation at a lower temperature using for example, but not limited to, copper based brazing materials such as Cu-Sil or Ti-Cu-Sil, silver based brazing materials such as Silvaloy (Ag-Cu-Zn) or Gapasil (Ag-Pd-Ga), gold based brazing materials such as Au-Cu, Au-Cu-Ag, or Au-Cu-Ni, or palladium based braze materials such as Pd-Ni-Si. A capacitor ground metallization **223** is attached using solder or thermal-setting conductive adhesives **222** to the platinum iridium wire **218**. The platinum iridium wire can actually be of any noble material including platinum, gold, palladium, silver, ruthenium, rhodium, osmium, iridium, alloys based on each of these noble metals and combinations thereof. Leadwires or terminal pins **211** through **211'''** pass through the feedthrough capacitor and through the hermetic seal. This is best understood by referring to FIG. **26**, which is taken from section **26-26** from the structure of FIG. **25**.

FIG. **26** illustrates the laser weld **220**, the noble wire **218** (oxide-resistant metal addition) and the solder or thermal-setting conductive adhesive **222**. In FIG. **26**, one can see the capacitor interior electrode plate stacks. A ground electrode plate stack **230** and an active electrode plate stack are designated by **232'** and **232'''** which are connected respectively to terminal pins **211'** and **211'''**. It is understood by one skilled in the art that various structures and techniques are used to connect the active electrode plates to the leadwires. On the body fluid side of the capacitor, one can see gold brazes **226** and **228**. Gold braze **226** connects the ferrule **216** to the alumina insulator **224** providing a robust mechanical and hermetically sealed joint. Gold braze **228** forms a robust mechanical and hermetic seal between the alumina ceramic **224** and the leads **211**. An electrical connection **256** connects the capacitor inside diameter metallization **255** to the lead-wire **211**.

Referring once again to FIGS. **25** and **26**, one can see that the wire **218** as an oxide-resistant metal addition provides a very novel feature, that is, electrical connection material **222** does not directly attach to the ferrule **216**. The reason for this is that the ferrule is typically of titanium, which commonly forms titanium oxides. Titanium oxides are very resistive and can also act as semi-conductors. This means that a direct connection to titanium would degrade the effectiveness of the capacitor ground electrode plate stack. The noble wire **218** acts as an intermediate surface. By laser welding **220** the wire **218** to the titanium ferrule **216**, one forms a very strong oxide-resistant metallurgical bond. Now, the surface on wire **218** is relatively oxide free. For example, it could be gold, platinum, palladium, silver, ruthenium, rhodium, osmium, iridium, alloys based on each of these noble metals and combinations thereof which are oxide resistant at room temperatures. In fact, the wire **218** could be pure platinum and not platinum iridium. The reason for this is that the iridium can form undesirable oxides.

Referring once again to FIG. **26**, shown is that the gold brazes forming the hermetic seals **226** and **228** are on the body fluid side. There are a number of AIMD manufacturers that prefer having the gold braze on the body fluid side. By having the gold braze in this location, however, making a connection to the capacitor's outside perimeter or diameter metallization **223** to the same gold braze surface becomes impossible. In other words, as previously described in FIG. **18**, there is no possibility to provide the gold bond pad **165**, which is a contiguous part of the hermetic seal braze **226**. This is a major driving feature of the present invention in that a methodology is provided so that the feedthrough

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capacitor can be properly grounded to an oxide-resistant surface even when the gold brazes are disposed on the opposite side (opposite the body fluid side).

Referring back to FIG. **26**, one can see that there is an electrical pathway described as the electrical path from the capacitor internal ground electrode plate set **230** through the capacitor peripheral or exterior metallization **223** through the electrical connection material **222** to the noble wire **218** and laser weld **220** and then the ferrule **216** to thereby provide the electrical path having a total resistance of 5-milliohms and a total inductance of less than 10 nanohenries. In another embodiment, total resistance of this grounding path would be less than 1-milliohm and the total inductance would be less than 1 nanohenry. As used herein, the definition of the term "grounding pathway" is the aforementioned grounding pathway extending from the capacitor internal electrode plates all the way to the AIMD conductive housing **116**.

FIGS. **27-28** are similar to FIGS. **25-26** but now show a peninsula structure **244** formed as part of the ferrule **216**. A ground pin **242** is attached to the peninsula **244**. As can be seen best in the cross-section of FIG. **28**, the ground wire **242** is not connected to the ground electrode plates **230**. The ground electrode plates are still electrically coupled to the metallization **223** which is then electrically coupled to the ferrule **216** through the weld **220**, the wire **218** and the thermosetting conductive adhesive **222** or solder.

Referring once again to FIG. **27A**, one can see that the grounded peninsula **244**, which is a continuous part of the machined ferrule **216**, is electrically attached via material **219** to the ground pin **242**. The ground material could be a laser weld, a gold braze, a solder, a thermal-setting conductive adhesive, or the like. In general, ground pin **242** is provided as a convenience to the AIMD manufacturer to either ground the internal circuit board, or to provide an addition pacing vector to a conductor of an implanted lead (not shown) or both. The electrical ground attachment from the peninsula **244** to ground pin **242** is very low in resistivity, meaning that it would also be applicable for high voltage implantable cardioverter defibrillator applications. In such an application, a very high shock current would flow through this ground joint to an external electrode (not shown).

FIG. **28A** is an enlarged view of a new embodiment of the structure from FIG. **28** taken from lines **28A-28A** now showing the noble wire **218** as an oxide-resistant metal addition recessed into the ferrule **216**. In this way the wire **218** may be positioned and affixed in a more efficient manner.

FIG. **28B** is an enlarged view of another embodiment of the structure from FIG. **28** taken from lines **28B-28B** now showing the rectangular wire **218** as an oxide-resistant metal addition recessed into the ferrule **216**. In this way the rectangular wire **218** may be positioned and affixed in a more efficient manner.

The round wire illustrated in FIG. **28A** and the rectangular wire illustrated in FIG. **28B** are just two embodiments. An infinite number of drawn wire shapes are available to the designer in the present application. This can include a square wire, a triangular wire, an elliptical wire or any cross-sectional shape that one can imagine. Accordingly, the present invention is not limited to any particular geometry wire and is in fact, inclusive of all possible geometries. As will be further illustrated, the oxide-resistant metal additions of the present invention may also be comprised of clad wire. An example of a clad wire would be one with platinum cladding over an inexpensive copper core. The

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purpose of cladding is to provide an oxide resistant surface, but also reduce the cost by minimizing the use of precious metals.

FIG. 28C shows a perspective view similar to FIG. 27A now with the recess 231 and inserts 233 clearly shown. The inserts 233 are placed in the recess 231 before the wire 218 is placed and may be gold metal, gold brazed or any of the material variations and connection methods already described herein.

FIG. 29 is similar to FIG. 25 and illustrates that the two wires 218 could be replaced by a number of pads 234 serving as an oxide-resistant metal additions as shown. In general, the pads could be formed as a continuous part (not shown) of the machining of the ferrule 216 or they could be added as a subsequent assembly by gold brazing or laser welding 220 as shown. The pads 234 serving as oxide-resistant metal additions would be of the same noble materials previously described for the wire 218. This means that a convenient oxide resistant electrical connection 222 could be made using solder or thermal-setting conductive adhesives.

Throughout the invention, the intermediate biostable and oxide resistant intermediate metal addition, such as wire 218 shown in FIG. 27 with pads 234, 234a and 234' as illustrated in FIGS. 29 and 30, must have the following properties: 1) they must be weldable or brazable to the titanium ferrule 216; 2) this weld or braze joint 220 must break through any oxides of titanium and form a metallurgical bond between the structure 218 or 234 and the ferrule 216; and 3) the intermediate biostable oxide-resistant metal addition wire 218 or pad 234 must be connectable to the capacitor's external metallization 223. The number of connection methods to the capacitor's external metallization is limited. This includes solders, solder paste and all types of thermal setting conductive adhesives. In general, although possible, it is not reliably possible to braze or weld directly to the capacitor's external metallization 223, hence this option is not a preferred embodiment. In summary, the biostable wire 218 or pad 234 need not be platinum, but it can consist of a long list of metals, alloys based on these metals and combinations thereof that would meet the above criteria. Choices would be gold, palladium, tantalum, and niobium, alloys based on these metals and combinations thereof. Additional non-limiting considerations include: tungsten, iridium, ruthenium, rhodium, silver, osmium, alloys based on these metals and combinations thereof. Other nonlimiting examples include platinum based materials such as platinum-rhodium, platinum-iridium, platinum-palladium, platinum-tungsten, platinum-ruthenium, platinum-gold, gold-palladium, gold-silver, silver-palladium, gold-platinum and naturally occurring alloys like platinumiridium (platinum-iridium), iridosmium and osmiridium (iridium-osmium).

It will be appreciated that the pad 234 could also be clad as previously described, to the various wires 218 of FIG. 25 and on.

FIG. 30 is a sectional view taken from section 30-30 from FIG. 29 illustrating that the pads 234 and 234' are disposed on both sides of the capacitor. It will be understood to those skilled in the art that they could also be disposed at the ends of the capacitor (not shown). It will be appreciated to one skilled in the art that the pads could be connected to each other. For example, referring once again to FIG. 27, pads 234 and 234a could be filled in between so that there is one large continuous pad. These pads could also have holes in them to further facilitate the electrical attachment between the pad and the capacitor external ground metallization 223.

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FIG. 31 is a perspective view of another embodiment similar to FIGS. 25-30 now showing a different configuration of pad 234 as an oxide-resistant metal addition. Here, pad 234 is shown in an L-shape. There is a hole in the bottom of the pad facilitating the laser weld or braze 220 to the ferrule 216. FIG. 32 is a sectional view taken along line 32-32 from the structure of FIG. 31.

FIG. 33 is a perspective view of yet another embodiment of a feedthrough capacitor assembly 210 similar to FIGS. 25-32. Here the pad 234 as an oxide-resistant metal addition is a long pad that spans the length of the long side of the capacitor 212. The pad 234 has a large hole to facilitate the placement and bonding of the conductive adhesive 222.

FIG. 34 is a sectional view taken from section 34-34 from FIG. 33. It shows the long bracket 234 cross-section along with laser weld or braze 220.

FIG. 35 is similar to FIG. 25 except in this case there are more terminal pins 211. Accordingly, it is necessary that the oxide-resistant metal addition wire 218 be longer and have more laser welds 220 to the ferrule 216. This is because it would be undesirable to have a relatively long distance between a filtered terminal pin and its associated ground. This is because inductance and resistance can build up across an internal ground plane, thereby degrading the RF filtered performance of a distal filtered pin. FIG. 36 is an exploded view of the structure of FIG. 35. In FIG. 36, the ground pin 242 is shown laser welded 219 or gold brazed 219 into the ferrule 216 in the peninsula area 244. In this case, the capacitor is a conventional capacitor wherein the ground electrode plates are terminated with metallization 223 disposed along the two long outside ends of the capacitor 212. In this case, there is no connection between ground pin 242 and the capacitor's ground electrode plate stack 230. In a different embodiment (not shown), a capacitor's ground electrode plates could be connected to this grounded pin as completely described in U.S. Pat. No. 5,905,627, the contents of which are incorporated herein by reference. Referring once again to FIGS. 35-37, an alternative is given wherein a direct connection to terminal pin 242 and the grounding of the capacitor's electrode stacks 230 is nonexistent. That is, the electrical connection is between the capacitor metallization 223 and the noble wires 218.

FIG. 37 is a sectional view taken from section 37-37 from FIG. 35 illustrating that any one of the active terminal pins 211, 214 passes through feedthrough holes near the center of the capacitor 212 in a staggered pattern where the pin 211, 214 makes contact with its own individual set of active electrode plates or many active electrode plates 232. The ground electrode plates 230 contact the capacitor's long-side perimeter metallization 223 and then electrical attachment material 222, which can be solder or thermal-setting conductive adhesive, attaches the capacitor ground metallization 223 to the noble wire 218. The wire 218 can then be brazed or welded 220 to the ferrule 216.

FIG. 38 is similar to FIG. 35, which illustrates an alternative method of grounding the capacitor's ground electrode stack 230. Referring back to FIG. 36, one can see the novel ferrule peninsula 244 to which ground pin 242 is electrically and mechanically attached. In FIG. 28, ground pin 242 is electrically attached to the ferrule 216 and is thereby grounded in a similar manner as shown in FIG. 36. A novel L-shaped clip 246' as an oxide-resistant metal addition is electrically attached to ground pin 242 and engages a portion of the capacitor's external ground metallization 223. This is best illustrated in FIG. 38, where the ground clip 246', being electrically connected 222 to the capacitor's ground metal-

lization 223, is shown. Then, the ground pin 242 is electrically connected at 251 to the ground clip 246'.

Referring back to FIG. 38, illustrated is clip 246' as an oxide-resistant metal addition is disposed on the top surface of the capacitor 212. There is an insulating structure 252 that is disposed on top of capacitor 212. This can be a conformal coating of insulation, an insulation sheet with adhesive layer 253, or even an alumina ceramic thin sheet of insulation. For the case where this insulation sheet 252 is alumina ceramic, it may have a cut-out pocket so that the clip 246' drops down into it and fits flush with the top of the insulating layer 252. This would help to hold the clip 246' in place and to index it.

FIG. 39 shows the ground electrode plate 230 which does not make contact with the leadwires 211, 214 or the grounded wire 242. The ground electrode plate 230 makes contact with metallization 223 which is then in electrical contact with novel pad 246'.

FIG. 40 shows a multitude of active electrode plates 232 electrically coupled to the leadwires 211, 214. Note that the ground pin 242 lacks an active electrode plate 232.

FIGS. 41-43 are very similar to FIGS. 38-40. FIGS. 41-43 show a different embodiment of the novel pad 246a as an oxide-resistant metal addition. Pad 246a is longer along the length of increased metallization 223. This design would increase filter performance due to the shortened electrical pathways. In this way, the inductance across the ground planes of the capacitor is greatly reduced. This means that outer terminal pins 211', 214' will have improved attenuation and greater insertion loss than the structure previously illustrated in FIG. 38.

FIG. 44 is a sectional view for both FIGS. 38 and 41. One can see better the peninsula or extension 244 that attaches to the ground wire 242. Referring once again to FIG. 44, one can see that the peninsula structure 244 can alternatively be placed on the right side as opposed to the left side. In addition, peninsula 244 could be placed on both sides, which would mean that there would be two ground pins 242. In this way, metallization 223 could also be added to the right side of the capacitor so that the right side became a mirror image of the core structure 246' and ground pin 242. An advantage of having two ground pins 242 would be even lower inductance and resistance in the grounding path from the capacitor ground electrodes 230 through to the ferrule 216.

FIGS. 45A, 45B and 45C illustrate various types of L-shaped clips 246 as an oxide-resistant metal additions. In FIG. 45C, one can see the advantage of having a clip with an elliptical hole 247 because this allows electrical connection material 222, which can be a solder or a thermal-setting conductive adhesive, to be placed on the outside of the clip and also inside the elliptical hole. This increases the electrical contact area and thereby reduces the resistance as well as improves mechanical strength.

FIGS. 46 and 47 are an alternative embodiment of clip 246b previously illustrated in FIGS. 38 and 41. The novel clip 246b as an oxide-resistant metal addition is under the capacitor 212 sandwiched between the ferrule 216 and the capacitor 212. A hole 247 is also in the clip 246b to facilitate placement of conductive adhesive 222. FIG. 47 is an exploded view that best shows the shape of novel clip 246b.

In the alternative embodiment shown in FIG. 46, the clip 246b is disposed underneath the capacitor 212 and electrically and mechanically attached directly to the peninsula structure 244. Having the clip 246b disposed underneath the capacitor 212, and then coming up on the side as is illustrated, would improve the RF performance of the capacitor. Effectively, this would shorten the ground pin 242 to almost

zero thereby reducing the impedance and inductance of the ground clip 246b. A notch (not shown) could be put in the ferrule 216 of the hermetic terminal to facilitate the clip coming out through the bottom so that the capacitor 212 still would sit flush on top of the ferrule structure 216.

FIGS. 48-53 are similar to FIGS. 25-34 except that in this case pockets 248 and noble oxide-resistant metal additions or inserts 250 have been formed so that an oxide resistant electrical attachment 222 can be made between the capacitor ground metallization 223 and the ferrule 216. An alternative embodiment 250 is shown where first, a brazing perform, such as a gold braze perform 250a, is placed and then a platinum cap 250b as an oxide-resistant metal addition is placed over it. Alternative metals may be used as noted earlier. In addition, instead of a braze preform 250a, one could use a resistance weld or lower temperature brazes such as those listed previously with the Cu-Sil or Ti—Cu-Sil examples. Platinum pad 250b would be slightly longer in the length direction and slightly longer in the width direction than the underlying pre-form 250a. This overlaying would prevent it from reflowing and leaking out during a gold braze operation. In addition, the pad 250b would protrude above the surface of the ferrule. This turns out to be very convenient during electrical attachment of the feedthrough capacitor (not shown) outside perimeter metallization 223. In other words, the protruding pad 250b would provide a convenient stop for a solder paste, a solder pre-form or a thermal setting conductive adhesive (dispensed by robot). This is best understood by referring to FIGS. 48 and 49, which shows that a pocket 248 and 248a are first formed at the time of manufacturing the ferrule 216 of the hermetic seal subassembly 210. These pockets can be rectangular (as shown), can be rectangular with rounded ends or they can be round holes as illustrated as 248a or even a continuous groove or slot as illustrated in FIG. 53 as 248c. Into these pockets or grooves 248 can be placed a noble wire 218 as previously described in FIG. 25, or a material 250, such as CuSil or TiCuSil or any other material as disclosed earlier that can form a metallurgically sound bond to titanium while at the same time, providing an oxide-resistant surface to which electrical attachment 222 can form a solid bond.

Referring once again to FIG. 49, one can see that there is an alternative arrangement similar to that previously described in FIG. 48. In this case, a circular gold braze pre-form 250Ab could first be placed into the counter-bore hole 248a and then a platinum or equivalent cap 250Aa as an oxide-resistant metal addition could be placed over it. These could all be reflowed into place leaving a convenient area to make electrical attachment between the capacitor external ground metallization 223, through the oxide-resistant pad 250Aa, through the braze material 250Ab and, in turn, to the ferrule 216.

FIG. 50 is an isometric view of the quad polar feedthrough capacitor 212 shown mounted to the hermetically sealed ferrule assembly previously illustrated in FIG. 48. Shown is an electrical attachment material 222 between the capacitor ground metallization 223 that connects to the oxide-resistant connection pads 250, 250'. Referring once again to FIG. 50, one can see that there is metallization 223 on both short ends of the capacitor 212. This metallization 223 could extend along the long sides or, alternatively, along all perimeter sides of the capacitor. In the case where the length of the perimeter metallization 223 is made longer, then additional pockets and oxide-resistant pads 250 would be required.

FIGS. 51 and 52 illustrate the ground and active electrode plate sets of the capacitor 212 previously illustrated in FIG.

50. In FIG. 51, shown is that the ground electrode plate 230 does not make contact with any of the terminal pins 211, 214. The metallization 223 contacts the ground electrode plate set 230 on its left and right ends. FIG. 52 illustrates the active electrode plates 232. In this case, the active electrode plates 232 are connected to each one of the feedthrough terminal pins 211, 214.

FIG. 53 is the same ferrule as previously described in FIGS. 49 and 50 except that instead of a discrete number of machined pads 248, there is a continuous groove 248c formed around the entire perimeter of the capacitor. This would be filled with Cu-Sil or Ti—Cu-Sil or any other material previously listed to form an oxide resistant connection area for the feedthrough capacitor (not shown). A feedthrough capacitor 212, in this case, would have perimeter metallization 223 along all four of its perimeter sides. Either a continuous or a multiplicity of short electrical connections 222 would be made between the capacitor metallization 223 and the gold braze or equivalent material that has been flowed in the trough 248c (not shown).

FIGS. 54 and 55 are yet another embodiment of the present invention. As shown in FIG. 54, gold films 250b may be placed on top of the ferrule 216. Then a conductive sheet 254 is laid overtop the gold films 250b. In a brazing procedure the gold films or plates bond between the conductive sheet 254 and the ferrule 216. The capacitor 212 can be placed on top of the conductive sheet 254 and then an electrical connection using conductive adhesives 222 can be made between the external metallization 223 and the conductive sheet 254. As shown in FIGS. 54 and 55, the metallization is around the entirety of the capacitor 212. This design would also reduce both the inductance and equivalent series resistance of the capacitor 212. The conductive sheet 254 is of a different material as compared to the ferrule 216 and the gold films 250b, and therefore forms an oxide resistant metal addition.

FIG. 56 is similar to FIG. 28 where the gold brazes 228 for the leadwires are directed to the body fluid side. In FIG. 28, the alumina insulator 224 is hermetically sealed with gold braze 226 to the ferrule 217 which is shown with the gold braze 226 between a ferrule 216 inner wall surface and the outside wall of the alumina ceramic insulator 224. FIG. 56 is different in that the gold braze 226 is between the top of the ferrule or a step towards the top of the ferrule 216 and is not between a ferrule or insulator side wall. Referring once again to FIG. 56, one can see that there is a clip structure 234, which is similar to the clip structure 234 previously illustrated in FIG. 33. The clip 234 has an opening to receive a solder or thermal setting conductive adhesive 222 as shown. In general, this clip structure 234 will be an oxide-resistant metal addition in accordance with the present invention, which may be welded or brazed 220 to the ferrule 216.

FIG. 57 is very similar to FIG. 56 except that in this case, the ferrule 216 does not have a step. Instead, the gold braze 226 is formed between the top face of the ferrule 216 and the bottom of the step on the alumina ceramic insulator 224.

FIG. 58 is very similar to FIG. 26 except that the terminal pins 211, 214 are discontinuous. There are actually two different subassemblies in FIG. 58. The lower subassembly is the hermetic seal subassembly, which is formed in a single process in a gold brazing furnace, thereby connecting a hermetic seal gold braze 226 between the ferrule 216 and the alumina insulator 224 and another gold braze 228 between the leadwire portions 214 and the alumina insulator 224. As part of this pre-assembly, the oxide-resistant metal addition wire 218 is gold brazed or laser welded 220 to the ferrule

216. In a separate manufacturing operation, the capacitor structure is fabricated, including its monolithic structure of alternating ground and active electrode plates, and of the outside perimeter or diameter metallization 223 and the metallization 255 on the inside of the feedthrough holes. Also pre-assembled are leadwire portions 211. There is a major advantage to this structure in that, the leadwire portions 211 can be of non-biocompatible and of toxic material since they are completely enclosed within the hermetically sealed and biocompatible AIMD housing. In other words, leadwire portions 211 never come into contact with bodily fluids or tissue. Therefore, leadwire portions 211 could be insulated copper wires or the like. In general, they are soldered or installed by a thermal-setting conductive adhesive 256 into the capacitor subassembly. The capacitor subassembly is then joined to the hermetic seal subassembly by a means of a ball grid array (solder), a thermal-setting conductive adhesive, or the like 260. The left side of the cross-section in FIG. 58 shows that the space between the leadwire segments 211 and 214 is greater, thereby requiring a higher volume of connecting material 260 as opposed to the shorter distance illustrated in the right side of the drawing. In order to minimize the resistance and optimize the current carrying capabilities, the reduced amount of conductive material 260, as shown on the right, may have less resistance and more current carrying capabilities.

Referring once again to FIG. 58, capacitor 212 is a three-terminal feedthrough capacitor, also known as a planar array. FIG. 59 is similar to FIG. 58 except that instead of a multipole feedthrough capacitor, there are individual MLCC chip capacitors 212' employed. Chip caps mounted directly to a hermetic seal or to a substrate that is attached to a hermetic seal are described in U.S. Pat. Nos. 5,650,759 and 5,896,627, the contents of which are incorporated herein by reference. A major disadvantage of these two patents is they do not provide any way of connecting to the ferrule (ground) in an oxide-resistant manner. Referring once again to FIG. 59, one can see that the oxide-resistant metal addition 218 of FIG. 58 has been replaced on the left side by an L-shaped oxide-resistant wire 234 and on the right, by a square shaped oxide-resistant wire 218. As previously stated, in the present invention wires can be drawn into a multitude of cross-sections that are not limited to any one shape. Referring to FIG. 59, chip capacitor 212' is a two-terminal MLCC.

FIG. 60 is very similar to FIG. 58 except that there are no gold brazes between the alumina insulator 224 and the corresponding leadwire segment 214. In this case, the leadwire segment 214 are co-fired with the alumina ceramic 224 to form a homogeneous structure. One can see that there are layers of conductive circuit traces 262 embedded in the alumina substrate. The purpose of this is to further improve the hermeticity of the structure. On the left hand side of FIG. 60, there is a leadwire 211 which is continuous and is co-fired into the alumina ceramic structure 224. On the right side, there is a short pin 211b that is co-fired into the alumina ceramic 224. This pin 211b is then joined by electrical connection material 256 to the leadwire segment 211a, which extends towards AIMD internal electronic circuits. The advantage to the structure showing on the right hand side of FIG. 60 is that leadwire segment 211a can be a standard tin copper lead (or other inexpensive non-biocompatible lead material). The circuit traces or layers 262, as shown in FIG. 60, are laid down in the green state (prior to sintering) of the alumina substrate 224. In other words, the alumina substrate is a monolithic structure that has internal circuit traces 262 which are staggered back and forth and then connected to each other by short segments of leadwire

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to form a continuous conductive path through the hermetic seal insulator **224**. The purpose of the staggering is to greatly improve the hermeticity and pull strength of the completed structure.

FIG. **61** is very similar to FIG. **59** except that in this case, there is a substrate or circuit board **264**, which is placed adjacent the top side of the hermetic seal subassembly. On the left side, the circuit board has circuit traces **263** and **263'** to which the monolithic ceramic capacitor (MLCC) **212'** is electrically and physically attached. The left side of the MLCC capacitor has an electrical attachment material **222**, which can be a solder, a thermal-setting conductive adhesive, or the like. It attaches the left hand capacitor metallization **225** to the circuit trace **263**. There is an additional electrical connection material **266**. The right hand side of FIG. **61** also shows an MLCC capacitor. It is known to those skilled in the art that the rectangular MLCC could be flipped around in its orientation.

FIG. **62** shows a co-fired alumina ceramic insulator **224** with solid filled vias **214a**, as shown. Typically these are co-fired into a single monolithic structure. For example, the structure of FIG. **62** is taught in U.S. patent publication 2014-0036409 (application Ser. No. 13/743,276), which is incorporated in full herein with this reference. The ceramic capacitor, which sits on top of the alumina ceramic insulator, has leadwire segments **211**, which can either be pre-installed or installed by soldering or thermal-setting conductive adhesive **256**, to thereby make an electrical and mechanical attachment to the solid filled vias **214a**. In accordance with the present invention, the outside diameter metallization **223** of the capacitor **212** is electrically connected with a solder or a thermal-setting conductive adhesive **222** to the oxide-resistant metal addition **218**. The oxide-resistant metal addition **218** can be brazed or welded **220** to the ferrule **216** in accordance with the present invention.

FIG. **63** is taken from section **63-63** from FIG. **62** showing what can happen during practical manufacturing using human or robotic dispensers. For example, if electrical connection material **222** is a solder or thermal-setting conductive adhesive, it can flow over the oxide-resistant metal addition **218** and down across its weld or gold braze **220** to the ferrule **216**. As shown in FIG. **63**, this material **222** could also flow all the way down to the ferrule (which is subject to oxidation). The purpose of this is to illustrate that when materials are flowing, they can flow over the top of previously placed materials. However, the primary electrical path of the present invention is still between electrical connective material **222**, the oxide-resistant metal addition **218** and its metallurgical attachment **220** to the ferrule **216**.

FIG. **64** is taken from section **64-64** from FIG. **62** and shows what the assembly of FIG. **62** would look like after a laser welding or brazing **220** of the oxide-resistant metal addition **218**. We can see that part of it has reflowed or become molten and metallurgically bonded with the titanium of the ferrule **216**. This metallurgical bond is illustrated by **220**, but as can be seen in FIG. **64**, it would be more normal that it would have an irregular shape, as illustrated.

FIG. **65** is very similar to section **63-63** taken from FIG. **62** except that in this case, the oxide-resistant metal addition **218** is a clad wire, which has an intercore **268** and an outer cladding **270**. There are many types of clad wire readily available, including laser clad wire wherein cladding is achieved using a powdered or wire feedstock metal that is melted and consolidated by use of a laser to clad the core metal. Additionally, this enables mixed geometry cladding options, and particular ones that pose manufacturability challenges from traditional cladding methods. As one

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example, a platinum clad silver or copper wire would be much cheaper than a solid platinum one and would still provide an oxide-resistant metal addition. Other types of clad wires include gold clad stainless steels, palladium clad MP35N, palladium clad Ni—Co—Cr—Mo alloys, platinum clad molybdenum, platinum iridium clad niobium, platinum clad tantalum, silver clad nitinol, silver clad nickel titanium alloys, gold clad nickel titanium alloys, platinum alloy clad molybdenum, gold alloy clad stainless steels, gold clad tantalum and other similar noble metal and noble metal alloy cladding of lower cost core metal option combinations. Such cladding/core options may customer specified combinations as appropriate for the application performance demands and any combination of the cladding and core metal as given above are options. Additionally, more than one cladding layer may be used to achieve specific application performance needs.

FIG. **66** is very similar to FIG. **65** except in this case, the clad wire is square instead of round. Again, any geometry wire can be clad and the present invention is not limited to any one particular shape of extruded wire.

Although several embodiments have been described in detail for purposes of illustration, various modifications may be made to each without departing from the scope and spirit of the invention. Various features of one embodiment may be incorporated into another embodiment, as each embodiment is not exclusive of the other features taught and shown herein. Accordingly, the invention is not to be limited, except as by the appended claims.

What is claimed is:

1. A hermetically sealed filtered feedthrough assembly for an implantable medical device, the filtered feedthrough assembly comprising:

- a) a ferrule of an electrically conductive material, the ferrule comprising a ferrule sidewall defining a ferrule opening, wherein the ferrule comprises a ferrule extension partially extending into the ferrule opening;
- b) an insulator of electrically non-conductive material, the insulator comprising an outer insulator surface extending longitudinally from a first insulator end to a second insulator end, wherein the insulator is hermetically sealed to the conductive ferrule sidewall in the ferrule opening, and wherein the insulator has at least a first insulator bore extending there through to the first and second insulator ends;
- c) a filter capacitor, comprising:
  - i) a dielectric comprising an outer dielectric surface extending longitudinally from a first dielectric end to a second dielectric end, wherein the second dielectric end is longitudinally disposed adjacent to the first insulator end;
  - ii) at least one active electrode plate supported by the dielectric in an interleaved, partially overlapping relationship with at least one ground electrode plate;
  - and iii) at least a first and a second dielectric bores extending through the dielectric to the first and second dielectric ends;
- d) a first metallization electrically contacted to the at least one active electrode plate in the first dielectric bore;
- e) a conductor comprising an electrically conductive material hermetically sealed and disposed through the first insulator bore, wherein the conductor is in a non-conductive relation with the conductive ferrule and extends through the dielectric bore so that a first conductor end is adjacent to the first dielectric end and a second conductor end is adjacent to the second insulator end;

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- f) a first electrically conductive material coupling the conductor in the dielectric bore to the first metallization coupled to the active electrode plate;
- g) a second metallization electrically contacted to the ground electrode plate at at least a portion of the outer dielectric surface; and
- h) a ground conductor extending through the dielectric in a non-conductive relation with the active and ground electrode plates, wherein the ground conductor has a first ground conductor end spaced from a second ground conductor end, and wherein the second ground conductor end is electrically and physically coupled to the ferrule extension; and
- i) an oxide-resistant metal addition electrically and physically coupling from the second metallization contacted to the ground electrode plate at the outer dielectric surface to a location on the ground conductor spaced from the second ground conductor end coupled to the ferrule extension.

2. The assembly of claim 1, wherein the dielectric is disposed between where the oxide-resistant metal addition is coupled to the ground conductor and the second ground conductor end coupled to the ferrule extension.

3. The assembly of claim 2, including an insulative sheet partially disposed between the first dielectric end and the oxide-resistant metal addition.

4. The assembly of claim 1, wherein the oxide-resistant metal addition is coupled to the ground conductor intermediate the second insulator end and the second ground conductor end coupled to the ferrule extension.

5. The assembly of claim 4, including an insulative sheet disposed between the second dielectric end and the insulator.

6. The assembly of claim 1, wherein the oxide-resistant metal addition is coupled to the second metallization contacted to the ground electrode plate by a second electrically conductive material.

7. The assembly of claim 6, wherein the second electrically conductive material comprises a plurality of connections electrically coupling the oxide-resistant metal addition to the second metallization.

8. The assembly of claim 1, wherein the oxide-resistant metal addition is coupled to the ground conductor by a third electrically conductive material.

9. The assembly of claim 1, wherein the oxide-resistant metal addition comprises a different material as compared to the ferrule.

10. The assembly of claim 1, wherein the oxide-resistant metal addition comprises a noble metal.

11. The assembly of claim 1, wherein the oxide-resistant metal addition is selected from the group consisting of gold, platinum, palladium, silver, and combinations thereof.

12. The assembly of claim 1, wherein a grounding pathway is defined from the second metallization, through the oxide-resistant metal addition and to the ferrule extension.

13. The assembly of claim 12, wherein a total resistance of the grounding pathway is less than 5 milliohm.

14. The assembly of claim 12, wherein a total resistance of the grounding pathway is less than 1 milliohm.

15. The assembly of claim 12, wherein a total inductance of the grounding pathway is less than 10 nanohenries.

16. The assembly of claim 12, wherein a total inductance of the grounding pathway is less than 1 nanohenrie.

17. The assembly of claim 1, wherein first conductor end is spaced from the first dielectric end and a second conductor end is spaced from the second insulator end.

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18. The assembly of claim 1, wherein the oxide-resistant metal addition is selected from the group consisting of an L-shaped pad and an L-shaped pad with cutouts.

19. The assembly of claim 1, wherein the filter capacitor is a feedthrough capacitor.

20. The assembly of claim 1, wherein the conductor comprises a leadwire selected from the group consisting of platinum, palladium, silver, and gold.

21. The assembly of claim 1, wherein the first insulator end is flush with the ferrule adjacent to the second dielectric end.

22. The assembly of claim 1, wherein the insulator and the filter capacitor are either circular or rectangular in cross-section perpendicular to their longitudinal extent.

23. A hermetically sealed filtered feedthrough assembly for an implantable medical device, the filtered feedthrough assembly comprising:

a) a ferrule of an electrically conductive material, the ferrule comprising a ferrule sidewall defining a ferrule opening, wherein the ferrule comprises a ferrule extension partially extending into the ferrule opening;

b) an insulator of electrically non-conductive material, the insulator comprising an outer insulator surface extending longitudinally from a first insulator end to a second insulator end, wherein the insulator is hermetically sealed to the conductive ferrule sidewall in the ferrule opening, and wherein the insulator has at least a first insulator bore extending there through to the first and second insulator ends;

c) a filter capacitor, comprising:

i) a dielectric comprising an outer dielectric surface extending longitudinally from a first dielectric end to a second dielectric end, wherein the second dielectric end is longitudinally disposed adjacent to the first insulator end;

ii) at least one active electrode plate supported by the dielectric in an interleaved, partially overlapping relationship with at least one ground electrode plate; and

iii) at least a first and a second dielectric bores extending through the dielectric to the first and second dielectric ends;

d) a first metallization electrically contacted to the at least one active electrode plate in the first dielectric bore;

e) a conductor comprising an electrically conductive material hermetically sealed and disposed through the first insulator bore, wherein the conductor is in a non-conductive relation with the conductive ferrule and extends through the dielectric bore so that a first conductor end is spaced from the first dielectric end and a second conductor end is spaced from the second insulator end;

f) a first electrically conductive material coupling the conductor in the dielectric bore to the first metallization coupled to the active electrode plate;

g) a second metallization electrically contacted to the ground electrode plate at at least a portion of the outer dielectric surface; and

h) a ground conductor extending through the dielectric in a non-conductive relation with the active and ground electrode plates, wherein the ground conductor has a first ground conductor end spaced from a second ground conductor end, and wherein the second ground conductor end is electrically and physically coupled to the ferrule extension; and

i) an oxide-resistant metal addition electrically and physically coupling from the second metallization contacted

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to the ground electrode plate at the outer dielectric surface to a location on the ground conductor spaced from the second ground conductor end coupled to the ferrule extension,

- j) wherein a grounding pathway is defined from the second metallization, through the oxide-resistant metal addition and to the ferrule extension, wherein a total resistance of the grounding pathway is less than 5 milliohm and wherein a total inductance of the grounding pathway is less than 10 nanohenries.

24. The assembly of claim 23, wherein the total resistance of the grounding pathway is less than 1 milliohm and the total inductance of the grounding pathway is less than 1 nanohenrie.

25. The assembly of claim 23, wherein the dielectric is disposed between where the oxide-resistant metal addition is coupled to the ground conductor and the second ground conductor end coupled to the ferrule extension.

26. The assembly of claim 23, wherein the oxide-resistant metal addition is coupled to the ground conductor intermediate the second insulator end and the second ground conductor end coupled to the ferrule extension.

27. A hermetically sealed filtered feedthrough assembly for an implantable medical device, the filtered feedthrough assembly comprising:

- a) a ferrule of an electrically conductive material, the ferrule comprising a ferrule side all defining a ferrule opening, wherein the ferrule comprises a ferrule extension partially extending into the ferrule opening;
- b) an insulator of electrically non-conductive material, the insulator comprising an outer insulator surface extending longitudinally from a first insulator end to a second insulator end, wherein the insulator is hermetically sealed to the conductive ferrule sidewall in the ferrule opening, and wherein the insulator has at least a first insulator bore extending there through to the first and second insulator ends;
- c) a filter capacitor, comprising:
  - i) a dielectric comprising an outer dielectric surface extending longitudinally from a first dielectric end to a second dielectric end, wherein the second dielectric end is longitudinally disposed adjacent to the first insulator end;
  - ii) at least one active electrode plate supported by the dielectric in an interleaved, partially overlapping relationship with at least one ground electrode plate; and
  - iii) at least a first and a second dielectric bores extending through the dielectric to the first and second dielectric ends;
- d) a first metallization electrically contacted to the at least one active electrode plate in the first dielectric bore;
- e) a conductor comprising an electrically conductive material hermetically sealed and disposed through the first insulator bore, wherein the conductor is in a non-conductive relation with the conductive ferrule and extends through the dielectric bore so that a first conductor end is spaced from the first dielectric end and a second conductor end is spaced from the second insulator end;
- f) a first electrically conductive material coupling the conductor in the dielectric bore to the first metallization coupled to the active electrode plate;
- g) a second metallization electrically contacted to the ground electrode plate at at least a portion of the outer dielectric surface; and

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- h) a ground conductor extending through the dielectric in a non-conductive relation with the active and ground electrode plates, wherein the ground conductor has a first ground conductor end spaced from a second ground conductor end, and wherein the second ground conductor end is electrically and physically coupled to the ferrule extension; and

- i) an oxide-resistant metal addition electrically and physically coupling from the second metallization contacted to the ground electrode plate at the outer dielectric surface to a location on the ground conductor spaced from the second ground conductor end coupled to the ferrule extension;

- j) a second electrically conductive material coupling the oxide-resistant metal addition to the second metallization contacted to the ground electrode plate by; and

- k) a third electrically conductive material coupling the oxide-resistant metal addition to the ground conductor;

- l) wherein a grounding pathway is defined from the second metallization, the second electrically conductive material, through the oxide-resistant metal addition, to the ferrule extension then the third electrically conductive material and the ground conductor.

28. A hermetically sealed filtered feedthrough assembly for an implantable medical device, the filtered feedthrough assembly comprising:

- a) a ferrule of an electrically conductive material, the ferrule comprising a ferrule sidewall defining a ferrule opening, wherein the ferrule comprises a ferrule extension partially extending into the ferrule opening;
- b) an insulator of electrically non-conductive material, the insulator comprising an outer insulator surface extending longitudinally from a first insulator end to a second insulator end, wherein the insulator is hermetically sealed to the conductive ferrule sidewall in the ferrule opening, and wherein the insulator has at least a first insulator bore extending there through to the first and second insulator ends;
- c) a filter capacitor, comprising:
  - i) a dielectric comprising an outer dielectric surface extending longitudinally from a first dielectric end to a second dielectric end, wherein the second dielectric end is longitudinally disposed adjacent to the first insulator end;
  - ii) at least one active electrode plate supported by the dielectric in an interleaved, partially overlapping relationship with at least one ground electrode plate; and
  - iii) at least a first and a second dielectric bores extending through the dielectric to the first and second dielectric ends;
- d) a first metallization electrically contacted to the at least one active electrode plate in the first dielectric bore;
- e) a conductor comprising an electrically conductive material hermetically sealed and disposed through the first insulator bore, wherein the conductor is in a non-conductive relation with the conductive ferrule and extends through the dielectric bore so that a first conductor end is adjacent to the first dielectric end and a second conductor end is adjacent to the second insulator end;
- f) a first electrically conductive material coupling the conductor in the dielectric bore to the first metallization coupled to the active electrode plate;
- g) a second metallization electrically contacted to the ground electrode plate at at least a portion of the outer dielectric surface; and

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- h) a ground conductor extending through the dielectric in a non-conductive relation with the active and ground electrode plates, wherein the ground conductor has a first ground conductor end spaced from a second ground conductor end, and wherein the second ground conductor end is electrically and physically coupled to the ferrule extension; and
- i) an oxide-resistant metal addition electrically and physically coupling from the second metallization contacted to the ground electrode plate at the outer dielectric surface to the ferrule electrically connected to the ground conductor.

\* \* \* \* \*

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UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 9,427,596 B2  
APPLICATION NO. : 14/826229  
DATED : August 30, 2016  
INVENTOR(S) : Jason Woods et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title Page

Page 5, Column 2, (56) References Cited OTHER PUBLICATIONS, lines 15-16, after the word “Tissues”, delete the redundancy “Parametric Models for the Dielectric Spectrum of Tissues”

Page 6, Column 1, (56) References Cited OTHER PUBLICATIONS, last line, delete “systems” and insert --Systems--

Page 6, Column 2, (56) References Cited OTHER PUBLICATIONS, line 10, delete “mri: a” and insert --MRI: A--

Page 6, Column 2, (56) References Cited OTHER PUBLICATIONS, line 15, delete “immune” and insert --Immune--

In the Claims

Column 22, lines 55-57 (Claim 1, lines 25-27) after the word “and” delete “iii) at least a first and a second dielectric bores extending through the dielectric to the first and second dielectric ends;”

Column 22, line 58 (Claim 1, lines 25-27) above line 58 of Column 22 having the words “d) a first metallization electrically contacted to the at least” insert --iii) at least a first and a second dielectric bores extending through the dielectric to the first and second dielectric ends;--

Signed and Sealed this  
Twenty-second Day of November, 2016



Michelle K. Lee  
*Director of the United States Patent and Trademark Office*